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THE HISPANO-SUIZA MOTOR

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The following publication, entitled "The Hispano-Suiza Motor," is published for the information and guidance of all concerned.

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BY ORDER OF THE SECRETARY OF WAR:

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TABLE OF CONTENTS.

CHAPTER 1.—THE ORIGIN OF THE HISPANO-SUIZA MOTORS.

	Page.
Introduction	9
Model "E"	9
The 200 and 300 horsepower engine	9
General design of Hispano-Suiza models	10
The crank shaft	11
The cam shaft	11
The connecting rods	12
The pistons	12
The piston pins	13
The piston rings	13
The cylinder	13
Aluminum cylinder blocks	14
Enameling cylinder blocks	15
Enameling manifolds	15
The valves	15
Magneto installation	16
The valve-gear housing	16
The crank case	16
The oil-pressure relief valves	16
The magneto supports	17
Fitting the bearings	17
Care of the nuts	17
The cam-shaft bearings	18
Testing the valves	18
Piston rings	18
Piston protection	18
Fitting carburetors	18
Attaching magnetos	19
Assembly	19
First "run-in"	19
Block test	20
Disassembly for inspection	20
Final assembly and test	21
Preparing for shipment	21

CHAPTER 2.—CARE AND MAINTENANCE OF THE HISPANO-SUIZA MOTORS.

Uncrating	22
Installation suggestions	22
Starting the motor	23
Operating suggestions	23
Oil-pressure relief valve	26
Carburetor	26

Page.
Propeller hub 28
Machine-gun mechanism 29
Periodical inspection 29
Removal of engine 30

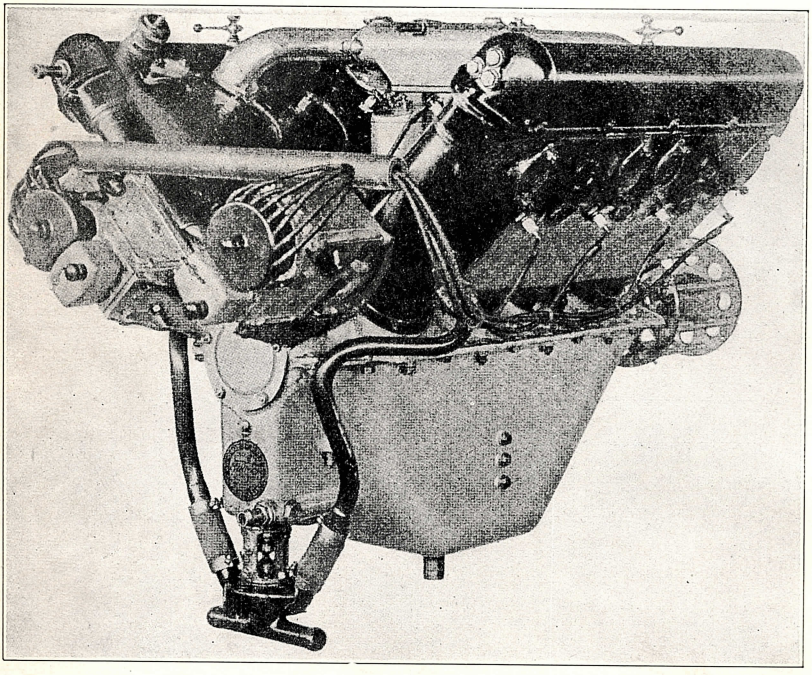
CHAPTER 3.—OVERHAULING THE HISPANO-SUIZA MOTOR, MODELS I AND E.

Brief survey of motor 31
Where to start the disassembly 31
Removal of spark plugs 31
Mounting the timing disk and scale 31
Removal and inspection of Tachometer drive 32
Removal of air pump 33
Removing cam-shaft housings 33
Determining direction of rotation and firing order 33
Checking the ignition wiring 34
Checking magneto timing 34
Ascertaining the valve timing 34
Removing and examining cam shafts and bearings 35
Removing magneto supports, gear housings, etc 36
Removing the magneto-drive assembly 36
Removal and inspection of water pump 37
Removal of cylinder blocks 38
Removing the pistons 38
Removing the rings and checking the pistons 38
Removing and examining valves and weighing springs 39
Removing and inspecting the vertical-drive shafts 39
Grinding valves 40
Preparing for removal of crank shaft 41
Removing the crank shaft and inspecting the crank case 41
Cleaning and inspecting the oil pump in crank case 42
Removing the connecting rods 42
The main bearing shells 43
Cleaning the upper half of crank case 43
Cleaning and adjusting the thrust bearing of the crank shaft 43

CHAPTER 4.—THE ASSEMBLY.

Introductory 45
Fitting new crank-shaft bearings 45
Checking the bearing fit and mating crank-case halves 45
Reaming the bearings and fitting end play clearance 46
Fitting bearings without a reamer 47
Fitting the connecting-rod bearings 48
Fitting piston pins 49
Assembling the crank shaft, connecting rods, thrust bearing, and ball bearing in the crank case 50
Assembling the pistons to the connecting rods 50
Assembling the cylinder blocks 52
Replacing the magneto-support bracket and oil sump pump assembly 52
Timing the valves 53
Table for advancing or retarding the timing of the cam shafts 53
Checking the timing on remaining valves after setting cam shaft 54

Page.
Correcting valve timing by aid of clearance ---- 54
Completing details on a cylinder block after timing valves ---- 55
Assembly of the right cylinder block ---- 55
Placing and timing the magneto ---- 55
Assembling the intake manifold and carburetor ---- 56
Attaching the gear-type oil pump ---- 57
Assembly of the water pump ---- 57
Connecting the water manifolds ---- 57
Placing the propeller hub ---- 58
Conclusion ---- 58



The Wright-Martin Hispano-Suiza.

THE HISPANO-SUIZA MOTOR.

THE HISPANO-SUIZA MOTOR

CHAPTER 1.

THE ORIGIN OF THE HISPANO-SUIZA MOTOR.

INTRODUCTION.

During the spring of 1916 the Société Hispano-Suiza of France presented the first Hispano-Suiza engine to the technical section of the French aviation. This was a stationary Vee type engine of 150 horsepower. This type A Hispano-Suiza was soon after adopted by the French military authorities. Fitted on the Spad plane, it was brought up to the front in August, 1916, and underwent the most severe practical tests during the Battle of the Somme. It was due largely to the performance of the Hispano-Suiza engine during this battle that the French were able to gain the supremacy of the air.

MODEL E.

The success of the type A 150 horsepower having been fully demonstrated, the Société Hispano-Suiza began experimenting with a new and more powerful engine, and in December, 1916, the type E 180 horsepower engine was produced. In general construction this engine was practically the same as the former type A, but the compression had been increased and a larger carburetor had been added. The engine was designed to run 300 revolutions faster, and was correspondingly reinforced. This engine gave more satisfaction than the first one. It had the great advantage of having high compression and allowed the pilot to keep his power at higher altitudes. The Germans at that time did not have very fast machines, and were trying to get the advantage in altitude. On that point they were beaten. Between 15,000 and 18,000 feet, where most of the fighting took place, the performance of the Hispano-Suiza engine was absolutely uniform and reliable.

THE 200 AND 300 HORSEPOWER ENGINE.

In March, 1917, the Société Hispano-Suiza produced a 200 horsepower engine which permitted an extra gun to be carried. This en-

gine was used throughout the Battle of the Aisne and in Flanders. In July a new type of 200-horsepower was manufactured. This was the 200-horsepower, high-compression motor. Very soon after the appearance of this engine, tests were made on the 300-horsepower Hispano-Suiza engine in service at the front.

GENERAL DESIGN OF HISPANO-SUIZA MODELS.

The general design of all models of the Hispano-Suiza are alike excepting the model A, which has the magneto supports arranged differently. The only way to distinguish the model E from the model I when uncrating is by a stenciled mark on the crank case between No. 4 left and No. 4 right cylinder, i. e., model E–M, indicating marine type connecting rods; model I simply denoting the I model. The model E is of the 180-horsepower type, the increased horsepower being obtained by increasing the distance from the center of the piston-pin holes to the top of the piston, thereby raising the compression, and, in addition, a larger carburetor with a barrel diameter of 2.18 inches is used. The carburetor is the twin type Stromberg NE–D5 and is used exclusively on the model E motor. As this motor is to run 300 revolutions faster than the model I or A, it is necessary to increase the spark advance to 25° before top center, whereas in models A and I the spark advance is 20° 20′ before top center. Four additional cylinder studs were added to withstand the high compression, and heavier connecting rods are used on this model. Model E and model I are both designed to run with a dry sump, and oil radiator and oil tank being used for the purpose of cooling the oil. An additional oil pump has been placed on the magneto support at the gear end of the motor on the models E and I to drain the crank case. The bore and stroke of all three models are alike; that is, 120 mm. bore with 130 mm. stroke. The models A and I Hispano develop 150 horsepower at 1,450 revolutions per minute at sea level, while the model E develops 180 horsepower at 1,800 revolutions per minute at sea level. The models A and I have a compression ratio of 4.72 to 1, due to the increased height of the piston. On the model A the magnetos are mounted on extensions of the two main surfaces of the upper half of the crank case and are driven from small gears located on the top of the lower vertical shaft gears, while on model I the magneto support is an aluminum casting bolted on the rear end of the crank cases. A small shaft, with a spiral gear, driven from the end of the crank shaft is mounted in the center of the magneto support. This shaft drives, by means of the spiral gear, another shaft which is at right angles to it and directly above it.

THE CRANK SHAFT.

The crank shaft is of the four-throw type, 180° between throws. It is made of chrome nickel steel, machined all over, and is hollowed for lightness. This shaft has four plain main bearings, bronze backed, and babbitt lined, and one annular ball main bearing at the magneto end. It is provided with a taper having a key for the propeller hub. To give an idea of the work necessary to complete a crank shaft, it has to undergo 86 operations before it passes the Government inspector's test, which is very rigid. Every part of the crank shaft is tested for hardness. The threads for the oil plugs and the threads for retaining the thrust bearing are tried with taps and dies for accuracy. A dial indicator is applied to the crank-shaft journals, testing same for cylindrical uniformity. This is done by placing the crank shaft on V blocks on a surface plate. A crank shaft which is out of line over 0.0015 of an inch is rejected. As the Hispano-Suiza motor may be used for either a tractor or pusher type plane without any radical change, the thrust bearing is designed to receive the thrust from either end, being a double-row ball adjustable thrust bearing located on the propeller end of the crank shaft. As the majority of the engines used on seaplanes are of the pusher type, the gear end of the crank shaft is designed so that a geared-down hand-cranking device may be used. Thus equipped, they are geared up to a small starting magneto which gives a hot spark at low engine speeds for starting.

THE CAM SHAFT.

The cam shafts are made of drop-forged, heat-treated, chrome nickel steel, drilled hollow for lightness and to allow an oil passage. The cams are machined on the cam shaft, great care being used to insure equal hardness on all sides of the cams. Each of the cam shafts is supported by three plain bronze bearings. The end of the cam shaft where the cam-shaft gear is to to be applied has five keyways, spaced equally around the circumference of the shaft, while the cam-shaft gear has only one keyway. By this method of spacing the keys numerous timing changes are affected, which is characteristic of this motor. The small holes that are found in each cam are placed there to provide lubrication of the valve tappets, valve stems, and noses of the cams. The drive for each shaft is by means of two pairs of bevel gears and a vertical shaft driven from the crank shaft by two vertical shafts and bevel gears of hardened alloy steel running in plain bronze bearings. These shafts are protected by a housing of light steel tubing, and each one is provided with a screw-driver type of joint near the middle, allowing ready removal of the

cylinder blocks without dismounting other parts. The cam shafts, cams, and heads of valve stems are all inclosed in oil-tight removable cast-aluminum housings.

THE CONNECTING RODS.

There are two types of connecting rods in use; one known as the marine type, used on the model E and a few of the model I motors; the other is known as the forked type and is used on the model A. The marine type is made of alloy steel, heat treated, machined all over, and drilled hollow for lightness. This type is generally used in connection with heavy-duty motors. One rod is forked at the bottom end, having a two-piece bronze box (babbitt lined) bolted to it by four bolts. This bears directly on the crank shaft. The other rod bears on the outer and central portion of the bronze box. Both connecting rods are provided with bronze bushings at their upper ends. Great care is exercised by the mechanics in fitting the connecting rod to the bronze box, Prussian blue being used on the flange and tried on the surface plate in order that they fit absolutely true. The forked-type rods are tubular in section, made of heat-treated alloy steel. The inside rod turns directly on the crank pin, while the outside one, which is forked, turns on the outside of the extended part of the former. The inner rod has its cap attached by two bolts and is babbitted both inside and outside on the boxes, which are integral with the rod. The outside rod is forked, the cap, which is attached by four bolts, being provided with a bridge piece to give stiffness. All babbitt is on the inside connecting rod. All machine work on the connecting rods is finished before the rod is dipped into the babbitt, the babbitt being held in place by holes in the shell upon which the babbitt is placed.

THE PISTONS.

The pistons are aluminum castings, three-eighths of an inch in thickness at the head. The sides taper from three-eighths of an inch at the top to one-eighth of an inch in thickness at the bottom. By this construction the heat is rapidly carried off. At the top of each piston are four narrow rings in two grooves. Near the bottom there is one oil ring, with relief just below it. Another model of piston has only two grooves at the top and one oil ring groove near the bottom. The piston pin is held in its position by a single set screw which passes completely through one end. It will be noted with this type of piston that the half-circular groove which carries the oil to the piston pins should always be turned toward the inside of the engine, the piston pins entering the piston at the side where the lock screw is located. The cotter pin, which safeties

the piston-pin set screw, will be located by turning the oil ring around until the ring gap is opposite the piston-pin set screw. If at any time this cotter pin has to be replaced, be sure that the head of the cotter pin is placed well down in the small indentation in the bottom of the ring groove, otherwise the ring will not fit its groove properly. Each piston is machined down to the desired width and should weigh within a half an ounce of each other. After the machine work is done on the piston, that is, ring grooves cut and piston-pin holes reamed, each piston is given a water pressure test of 60 pounds pressure. If no defects show under this test, the pistons are sent to another room to have the rings and piston pins fitted.

THE PISTON PINS.

The piston pins are made of casehardened alloy steel, large in diameter, and hollow. They are allowed to float in the pistons as well as the upper end of the connecting rods. Each is held in place by a piston-pin lock ring. The pistons are heated in a metal box under the workbench by steam heat. This is to allow for the expansion and to insure a perfect fit of the piston pins. This heat treatment is necessary in order to fit the pistons and piston pins properly. Care must be taken not to allow the pistons to expand more than they would under normal running conditions. Under these conditions when the pin is fitted correctly it should be a push fit by hand when oiled.

THE PISTON RINGS.

The piston rings are cast iron, concentric type, straight peened to insure roundness and perfect fit. Two rings are used in one ring groove, which reduces oil pumping and compression leakage to a minimum.

THE CYLINDER.

The individual cylinders are steel forgings, heat treated, machined and threaded on the inside. These steel sleeves are flanged at the bottom and closed at the top which is flat to provide for the two valve seats. Great care should be exercised by the mechanic in cutting the threads on these sleeves to get them absolutely true. The cylinder sleeve is about ten (10) inches in length and about one-eighth of an inch in thickness. There are about 7½ inches of threads cut on the cylinder sleeves, about 16 threads to the inch. The reason for the great number of threads is to bring the sleeve and the cylinder casting into more intimate contact, thereby conducting heat off faster than would otherwise be the case. Before the cylinder passes inspection, it is subjected to a water-pressure test of about 65 pounds. This

is done in order to detect any leakage. The valve seats are not drilled in the sleeve until the cylinder sleeve has been screwed into the casting blocks. The utmost accuracy is required of the mechanics in grinding the cylinder walls, only 0.001 of an inch being allowed each way. The cast aluminum cylinder blocks are fastened on a special stand, the water-jacket ports are plugged and a steam hose attached to one port. The steam is then turned on and the cylinder blocks are expanded in this manner much more than they would be under ordinary running conditions. This method is adopted in order to insure a tight fit of the cylinder sleeves. The sleeves are tried separately and fitted to their respective places in the cylinder blocks, bearing blue being used on the top of the cylinder sleeves to determine if the cylinder sleeves fit properly in the cylinder blocks. As the tops of the cylinder sleeves are perfectly flat, it is necessary that they fit snugly against the aluminum cylinder blocks; if high spots are indicated, they are scraped off with a special scraper. After the sleeves have been fitted to their particular places in the cylinder block, they are numbered and set aside with that particular cylinder block. Cylinder sleeves Nos. 1 and 3 are screwed into the cylinder block and are then placed in a milling machine, and the flanges are cut so as to allow cylinders 2 and 4 to be screwed into the cylinder block. After the cylinder sleeves have been screwed into the block the flanges are ground for trueness, and are then drilled so that they may be fastened to the studs on the crank case. The cylinder block is then fastened in a special machine and the valve seats for the four cylinders drilled in one operation. The cylinder block is again placed in another machine and holes drilled to receive the spark-plug bushings. The flanges are enameled and baked, which completes the cylinder block assembly.

ALUMINUM CYLINDER BLOCKS.

The aluminum cylinder blocks which form the water jackets and water ports, as well as intake and exhaust passages, are castings. The design of this cylinder casting has several peculiarities which make it different from any other cylinder assembly. After the casting has been made and the rough projections caused by molding have been removed, the cylinder block is subjected to a very rigid inspection to detect any flaws that may arise from faulty casting. If the blocks pass this test they are given a water-pressure test. The water test will show any defects that in the first inspection may have been overlooked. By using this method of inspection defective cylinder blocks are detected before receiving the final operations. Assuming that the blocks have passed the preliminary inspection, they are passed on to the various departments where the final operations are completed. Due to the peculiar cylinder construction it is necessary to use a

spark-plug bushing. This bushing prevents water leakage and also insures easy access to the spark plugs. As it is impracticable to screw the spark plugs directly into an aluminum housing, a steel bushing was adopted. These bushings are interchangeable, and in the event that spark-plug threads should be crossed, a bushing could be changed very readily without injury to the cylinder block assembly; whereas, in the case of the average motor, if the spark-plug threads were crossed it would necessitate changing the entire cylinder with undue loss of time. It will also be noted that the cast-iron valve guides are interchangeable. This also is one of the many advantages of this type of cylinder block assembly.

ENAMELING CYLINDER BLOCKS.

After all the machine work has been completed on the cylinder block assembly, the block is sent to the enamel test room, where it is to undergo several pressure tests. The water-jacket ports are plugged, excepting the lower portion, where a special pipe attachment is fastened. Enamel is then applied to the exterior of the casting and about 2 gallons of enamel is put into the water jacket and a pressure of about 70 pounds applied. This pressure forces the enamel into any small crevices in the casting which could not be detected by the water-pressure test. This pressure test acts doubly; it not only shows any defects in the casting, but at the same time fills the pores in the aluminum, making a faster water circulation possible, and entirely eliminating water leakage. After this, the block assembly is placed in an oven and baked for four hours to harden the enamel. At the end of the first baking period the casting is subjected to the same process of enamel pressure and again baked for four hours. The purpose of repeating this process is to assure the inspectors that the casting may be used in the final assembly, and by so doing about ten (10) per cent of the aluminum castings may be used, which without this enamel test may have been rejected. It will also be noted that the flat surface on top of the casting has been ground on a surface plate. This method insures an oil-tight joint.

ENAMELING MANIFOLDS.

The intake manifolds (T manifolds) and water pump body assembly also have enamel applied to their inner surfaces which is also baked on. By applying the enamel to the inner surfaces it further reduces resistance which generally occurs in manifolds.

THE VALVES.

The valves are set vertically in the cylinders along the center of each block and are directly operated by a single overhead cam

shaft. The valves are tungsten steel, with large diameter hollow stems, working in cast-iron bushings, provided at the upper ends with casehardened flat-headed adjustable screws (disks) against which the cams operate. To insure proper seating, each valve is held to its seat by two concentric helical springs, either one of which is sufficient to insure the valve seating in case of breakage to the other.

MAGNETO INSTALLATION.

Another feature of the Hispano-Suiza engine is the magneto installation combined with an adjustable coupling which makes positive breaker synchronization possible. The magnetos are held in place by an aluminum casting bolted on the gear end of the crank case. A small shaft, with a spiral gear, driven from the end of the crank shaft is mounted in the center of the magneto support. This shaft drives, by means of the spiral gear, another shaft which is at right angles to it and directly above it. The magnetos are driven from this upper shaft through gear-type couplings.

THE VALVE-GEAR HOUSING.

The valve-gear housing cover is designed to inclose the valve operation entirely, the bottom surfaces being ground on a surface plate to fit the ground surface of the top of the cylinder block assembly. The valve-gear housing cover also carries the air-pressure pump which is placed at right angles to No. 4 L exhaust valve and is operated by the same cam. The cam shaft and valve gear housing cover are so designed that the tachometer drive assembly may be attached to either the right or left block of cylinders, the attaching being optional according to the design of the ship.

THE CRANK CASE.

The crank case is an aluminum casting and is made in halves, the division being along the center line of the crank shaft. The main bearings are inserted in both the upper and lower halves. The upper half of the crank case is machined so that the cylinders form an angle of 90°. The lower half is of very deep section. This design of crank case adds materially to the strength of the engine. The oil pipe which supplies the main bearings is cast integral with the crank case. The sliding vane eccentric type of pump is mounted vertically directly below the gear end of the crank shaft in the lower half of the crank case, and is driven by the same bevel gear on the crank shaft that drives the vertical shafts.

THE OIL-PRESSURE RELIEF VALVES.

The oil-pressure relief valve and union, which allows for oil-pressure gauge connection, are placed on opposite sides of the crank-

case projection, which houses the oil pump. The oil filter is screwed into the bottom of this oil-pump housing.

THE MAGNETO SUPPORTS.

Extreme care is exercised by mechanics in fitting the magneto support. The base plates of the magnetos have been ground, as have the surfaces on the magneto supports. This method insures absolute alignment for the magneto coupling, and under no circumstances should any shims be used in mounting the magnetos to the magneto supports.

FITTING THE BEARINGS.

After both halves of the crank case have been finished they are ready to have the halves of the main bearings fitted. Considerable time is spent in the fitting of bearings to the case, bearing blue being used to insure a perfect fit. Dowel pins of the screw type are used to anchor the bearings in the upper half of the crank case to prevent the turning of the bearing. The dowel screws, however, are only necessary in the upper half, for, as one-half of the bearing is fastened, it will be impossible for the lower half of the bearing to turn. After the bearings have been fitted to both halves of the cases the case is bolted together and drawn up tight. After being tightly bolted an adjustable line reamer is run through, leaving the bearings 0.002 of an inch over size.

CARE OF THE NUTS.

The nuts used throughout this motor have been fitted to their particular studs and should be put back on the studs upon disassembly of the motor. Castellated nuts are used only on the connecting-rod bolts and the cam-shaft bearing studs, these being the only probable places where serious injury would result if nuts were to become loosened. In the reassembly of a motor it would require a half day's labor to safety all nuts with cotter pins. For the number of hours that a motor is in service it has been proven by experimenting that specially fitted nuts will maintain their tightness without being safetied, if drawn down properly. Special attention should be given the numerical order in which the connecting-rod bolts are placed on their respective rods, and in the reassembly this order should be strictly adhered to. The connecting rods are numbered to correspond with the numbers on the connecting-rod bolts, as in the case with the connecting-rod bolt nuts. With the fork-type connecting rod used, it has been a common occurrence to draw the connecting-rod bolt nuts too tight, thereby causing the bearing to bind, and in order

to prevent this, center punch holes have been made in the castellated nut, after the nut has been drawn sufficiently tight, to correspond with the like center punch holes on the connecting-rod bearing cap.

THE CAM-SHAFT BEARINGS.

The cam-shaft bearings are placed on a special cylinder block, bolted down tight as in service, and are line reamed to the desired fit. The cam-shaft bearing at the propeller end of the motor is designed so as to take the end thrust in either direction.

TESTING THE VALVES.

The valves are ground by hand and tested with pencil marks and are also subjected to a gasoline test. After the valve has been ground sufficiently it is then taken from the cylinder and four pencil marks are equally spaced around the valve seat. The valve is then put back in the cylinder and given one complete turn with the aid of a screw driver; the valve is again taken out, and if the marks have been removed by this turning it proves that the valve is seating properly and that the valve is touching on all sides of the seat. After all the valves in the cylinder block have undergone this pencil-mark test, the block is then removed from the special stand used in grinding and gasoline is put into the cylinders to test for leakage. This is an additional proof that the valve seating is perfect. The springs are then attached and the blocks laid aside for reassembly.

PISTON RINGS.

All piston rings used in the Hispano-Suiza motors are lapped in a special cylinder block, powdered pumice stone being used as the abrasive. By adopting this lapping method, a check on the fit of the piston ring is taken. Rings that do not have a perfect fit are, of course, rejected.

PISTON PROTECTION.

To prevent any injury to the pistons which might be caused by their striking against the cylinder studs before the cylinder blocks are mounted, a copper pipe with holes so spaced as to fit over the lower studs is used. In the event that any piston becomes scratched the defect is removed by rubbing the piston with an oilstone.

FITTING CARBURETORS.

Great care is used by the mechanics in fitting the carburetors to the T manifolds to see that the corresponding diameters of the mani-

folds and the barrel of the carburetor are exactly alike. If, however, this is not the case, the T manifold is scraped with a hand scraper until the desired inside diameter is obtained. If these precautions were not taken, condensation might result due to obstruction of the gas in the manifold.

ATTACHING MAGNETOS.

The magnetos are placed on the motor and are timed so that both magnetos will deliver a spark in the same cylinder at the same instant. One feature of the ignition system is the alphabetical lettering of the high-tension wires, whereas in most motors ignition wires are numbered. The lettering system facilitates to tracing the wiring system. It also will be noted that all wires leading out from the right-hand magneto are attached to the plugs on the inside of the V, while all wires from the left-hand magneto are attached to the plugs on the outside of the V. Should any trouble be experienced with the ignition system, this arrangement makes it very easy to find which side has the bad spark plugs by cutting the magnetos out of operation one at a time. If one or the other is cut out while the engine is running, the revolutions of the engine should not fall off more than about 20.

ASSEMBLY.

Since extreme accuracy has been exercised in the making of each part of the Hispano-Suiza motor, very little trouble is experienced in the assembly. After the crank case has been assembled and is ready to have the pistons attached, the pistons have been expanded so as to make the piston-pin assembly comparatively easy. It should also be noted that the numbers on the connecting rods face toward the propeller end of the motor and that the inner connecting rods, which are attached to the crank shaft first, are to operate in the left bank of cylinders. Cylinders are installed next upon the completion of the piston-pin assembly. Prior to the mounting of the cylinders the pistons are bathed in oil, and a special aluminum ring clamp used to hold the pistons, thereby reducing the ring breakage to a minimum.

FIRST "RUN IN".

Assuming that the assembly of all units is complete, the motor is then placed on a special stand where it is run in by means of a belt attached to a pulley, which is in turn driven by an electric motor. The crank case is filled with castor oil and the motor driven four hours. During this preliminary test strict attention is paid to all working parts to see that they are functioning properly.

BLOCK TEST.

After the expiration of this four-hour belt test the motor is taken to the test block where it is run under its own power. Numerous devices are used in connection with this test to record the efficiency of the motor, and to test its horse power. As the oil pressure relief valve is set to maintain the oil at 85 pounds, it is removed and a plug inserted in its place. This is done that the oil pressure may be sufficient to overcome the stiffness of the new motor. By removing the oil-pressure relief valve unlimited pressure in the oiling system can be had, limited by the revolutions per minute at which the motor is running. An oil tank is used while the motor is on the test block and is placed in a pan of water so that it will cool quickly. The temperature of the water is taken where it enters and where it leaves the water jacket. The gasoline tank is mounted on a scale and the amount of gas used per hour is recorded in pounds. Another feature of the Hispano-Suiza motor is that a small starting magneto or exciter is used to start the motor. By first turning the motor over two or three revolutions so that the cylinders may take in the mixture, then turning the handle of the starting magneto very rapidly, thereby causing a number of sparks to be delivered in the cylinder which is ready to fire, the motor will usually start, after which the magneto functions in the usual manner. This same device is used on the test block as well as in the fuselage. The motor is started and run for two hours at half speed, being constantly watched by a mechanic as to its performance. After running for two hours at intermediate speed, it is run at its maximum revolutions per minute for several hours.

DISASSEMBLY FOR INSPECTION.

At the expiration of this final test the motor is removed from the test block and taken to another department where it is to be disassembled for inspection. After the disassembly, every part of the motor is placed on a suitable bench to await the Government inspector. At this inspection every part is examined very closely for defects that may have shown up while the motor was subjected to the block test. If any parts have proven defective, they are set aside and replaced with new parts. In the course of a week's inspection numerous parts will have been rejected by the inspectors. When a sufficient number of rejected parts have accumulated they are assembled and are used for school motors. These motors may be used in test-block work at the different training schools throughout the country. Engines thus built are stamped " School motors—Not to be flown," and under no circumstances should a flight be attempted with a motor stamped in this manner.

FINAL ASSEMBLY AND TEST.

After the inspection the carbon is removed, valves ground, and the motor then reassembled. Upon completion of the assembly the motor is taken to another part of the building, where it is to undergo the fuselage test, which, incidentally, is the final test. The motor is installed in the fuselage and connected up as would be the case if it were installed in the completed ship. The tail of this fuselage is elevated, thereby putting the motor on a true flying level. The tail is also fastened to a large specially designed scale. The motor is started and after warming up sufficiently is run at its maximum revolutions per minute. On reaching the maximum speed the propeller will pull the fuselage forward, and at the same time the number of pounds the motor is pulling is indicated. Three different readings are required of each motor on this scale. First, the pull of the motor while on a true flying level; second, the pull of the motor while the fuselage is nosed up; and third, the thrust while the fuselage is nosed down. This test further assures the chief tester that the motor is in perfect condition. The motor is then taken from the fuselage and returned to the shop, the cylinders removed and valves reground. Then the motor is reassembled, inspected, and sent to the packing room for shipment.

PREPARING FOR SHIPMENT.

All steel and aluminum parts are slushed with heavy oil, and solid fiber gaskets are placed over exhaust ports and water outlets to prevent any foreign matter getting into the cylinders and water jacket. The following parts will be found covered with paper: Carburetor air inlet, propeller hub, water pump, tachometer drive, crank-case breather, vertical shafts, air pump, and magnetos. After the motor has been slushed with oil, and paper put on the parts named above, the motor is covered with a waterproof oilcloth and bolted down securely with six bolts to supports or sills fastened and braced to the bottom of the box. At the front end of the engine, under the propeller hub, will be found the spare parts and tool equipment box, the exciter or starting magneto being also fastened to the bottom of the box with two screws. The top is then placed over the motor and fastened to the bottom of the box with eight nuts. The box has suitable handles placed on each corner, making it convenient for handling the motor while crated. The shipping weight of the Hispano-Suiza motor when crated is about 870 pounds.

CHAPTER 2.

CARE AND MAINTENANCE OF THE HISPANO-SUIZA MOTORS.

UNCRATING.

To unpack, cut the four sealing wires, preferably at the bottom edge of the box. Remove the eight nuts which anchor the sides of the box to the bottom. The engine will be found securely fastened and braced to the bottom of the crate. Remove the nuts from these bolts and place two cables around each side of the engine between the steel sleeves. The engine can be lifted out with a suitable hoist. Do not attempt even partially to rest the weight of the engine on the lower half of the crank case or any part other than the separating flanges on the upper half of the case. Before shipping the Hispano-Suiza engines, all the steel and aluminum parts are slushed with heavy oil. A spray of gasoline will remove this oil from the engine. If the engine is to be started immediately after cleaning keep the magnetos dry or there will be danger of fire.

INSTALLATION SUGGESTIONS.

Assuming that the motor has been cleaned, and is to be fitted in the fuselage, the following method of installation is recommended for the Hispano-Suiza motor. The motor should be anchored on a rigid support which at the points of contact with the engine should be lined with fiber or sheet metal. The engine base should set flat on the engine support members. Contact should be positive at all places between the engine base and supports before the hold-down nuts are tightened. Whenever possible, the cam-shaft housings should be left exposed; their disassembly is then made easy and this arrangement permits the plane constructor to cut down the size of the cowls. If, in some cases, the engine is mounted without any cowls, some method of sheltering the magnetos should be provided for, such as a leather covering. The plane should be so designed that the following parts are easily accessible: Magnetos, particularly the distributors and breaker boxes, spark plugs, oil filter, oil-relief valve, and crank-case breather tube cap. The danger of back-fire should be reduced by fitting a long screen over the air inlet, the inside diameter of which should be about 4 inches and length about 6 inches, with a steel disk placed in the end.

At the lower part of the carburetor there is a nipple to which a small drainpipe should be fastened to carry off the gasoline. This pipe should discharge well to the rear, under the planes, and as far as possible away from the exhaust of the motor. A gasoline shut-off should be provided as near the engine as possible to enable the pilot to shut the gasoline supply. It is important that the airplane designer place the water radiator so that there is at least a 12-inch head above the highest part of the cylinder water space. When two side radiators are used they should be jointed, if possible, by a communicating tube on top. The circulating system should have at its highest point a small expansion tank with a level cock, which avoids complete refilling of the tank. This space in the tank, above the level cock, should have not less than 3 quarts capacity, to allow for the expansion of the water. It is necessary to locate, in an accessible manner, a filter between the cylinder outlets and each radiator, to stop sediment in the water, which deposits in the jackets and tends to clog the radiators. See that all water and oil connections are tight, and that the carburetor control rods are pinned in place at both ends and work freely. See that they function the carburetor control levers from one extreme to the other. Always take these precautions, remembering that any of them neglected may cause a forced landing.

STARTING THE MOTOR.

The starting magneto is a small magneto similar in construction to the larger ones. It is generally mounted in the cockpit of the plane in easy access of the pilot. One side of the starting magneto is connected to the brush in the center of the distributer on one of the running magnetos; the other side is grounded to the engine to complete the circuit. The engine is primed through the pet cocks on the intake manifolds and turned over compression several times. The man turning the engine over stands back and the pilot closes the ignition switch and turns the starting magneto by hand. This throws a shower of sparks into one of the running magnetos which are carried through the carbon brush to the spark plug of the cylinder which is ready to fire. The motor will start providing the mixture is correct. A starting magneto will always give a spark when turned regardless of the switch position or running magneto position. Therefore, never turn the starting magneto until the man cranking the engine stands away from the propeller and has given the proper signal. In starting the engine when it is cold, it is best to prime it through the pet cocks on the intake manifold.

OPERATING SUGGESTIONS.

The speed is controlled only by the throttle and the motor is found to start best with a very small throttle opening. The throttle

lever is connected to an operating lever in the pilot's cockpit. The second control lever on the carburetor is designed to correct the variations in carburetion required at the different altitudes and is also connected to an operating lever in the pilot's cockpit. For starting, and until the engine is warmed up, the altitude control lever should be in the rich, or all the way forward position. After the engine is warmed up the control can be moved toward the lean position until the maximum revolutions per minute of the motor is obtained. This adjustment will generally be found satisfactory up to about 3,280 feet. Above that height it is necessary to make corrections, which are always, of course, indicated by the revolution counter. As the altitude is increased it will be found necessary to move the lever to the lean position. Before trying to start the engine make sure that there is pressure in the gasoline tank, if a pressure system is used. Each motor should be tested in flight to determine the difference between the speed in the air and on the ground. The difference may vary from 50 to 300 revolutions per minute. It will be noticed that during a very steep climb or a very short turn or bank the engine will be temporarily overloaded, causing a slight decrease in the number of revolutions per minute, but will recover itself as soon as the plane regains normal position. After a motor is started the throttle should be left in approximately the starting position and the engine allowed to run at idling speed (about 800 revolutions per minute) for a few minutes or until the engine is thoroughly warmed. It is particularly essential with the Hispano-Suiza that great care be used in warming the motor and in cooling it after a long run.

Never attempt to crank an engine immediately after it has been stopped. An overheated spark plug or red-hot piece of carbon might cause preignition and a disastrous back kick result. Allow the engine to cool a few minutes before starting again.

In filling a gasoline tank always pour the gasoline through a chamois skin to free it from water and other impurities.

An air-pressure pump is provided on the left cylinder cover, operated by one of the cams. If this pump is used to keep pressure in the gasoline tank, a relief valve should be placed in the line to maintain a pressure of not over 2 pounds at the carburetor. The relief valve should be designed so that it can be adjusted during flight to correct for difference in altitude. When a pressure system is used, always make sure that there is pressure in the tank before trying to start the engine. This initial pressure is obtained by a hand pump, a pressure gauge on the dash indicating the amount of pressure. If a gravity-feed system is used, the tank should be arranged to give 1 to 2 pounds head at the carburetor for any position of the machine in flight. A vacuum system may also be used to draw the gasoline from the main tank to an auxiliary tank, the gasoline feeding from the

auxiliary tank to the carburetor by gravity. The vacuum is generally obtained by placing a compound Venturi in the draft of the propeller and taking a lead from its throat to the main gasoline tank, always, of course, placing a check valve in the line and having a branch line leading to the auxiliary tank. The gasoline line from the tank to the carburetor may be of copper tubing, but should have a rubber-hose connection at the carburetor at least 12 inches in length. This is a necessary precaution to prevent the vibration and weaving of the plane from breaking the copper tubing. The gasoline line should be of sufficient size to allow about 30 gallons of gasoline under 2 pounds pressure or 4-foot head to flow through it in one hour. In extremely cold weather it is advisable to stop the engine after three or four minutes' operation and wait a short time until the heat is communicated to all its parts. In order to facilitate starting in the morning and to free the rings, especially if castor oil be used as a lubricant, while the engine is still hot after the previous run it is advisable to inject a small amount of kerosene through the pet cocks of the inlet manifolds and turn the propeller over several times. During freezing weather fill the water-circulating system with a good anti-freezing solution. If alcohol is used, an extra amount should be added occasionally to make up for evaporation. Glycerin does not evaporate at ordinary temperatures and should not require replenishing. A simple solution of alcohol, while it is not injurious in any way, lowers the boiling point of the water. The boiling point of denatured alcohol is about 10° higher than that of wood alcohol. The use of glycerin raises the boiling point of the solution. It is more expensive than alcohol and is slightly injurious to rubber. All things considered, a combined use of alcohol and glycerin in water is the most satisfactory. Do not use any alkaline or calcium chloride solutions, as they are injurious to the metal parts.

The capacity of the radiator varies with the different types, but the area should be sufficient to maintain the desired water temperatures. The radiator should be fitted with adjustable shutters or an equivalent method of maintaining these temperatures in cold weather or at high altitudes, especially while taking long glides or nose dives. The Hispano-Suiza engines are equipped with a centrifugal type water pump which will handle about 26.50 gallons per minute at 1,450 revolutions per minute of the engine. The capacity of the cylinder water jackets is about 41 pounds, or approximately 5 gallons.

When fastening the tachometer shaft to the engine always allow about one thirty-second of an inch end play. The end play should be tried at different points during one complete revolution. The shaft might bind at one place and not at another, due to misalignment, provided the swivel is perfectly free before being assembled to the engine. Sometimes placing the swivel a half turn from the

original setting rectifies the trouble; if not, place a heavy washer under the tachometer housing where it screws into the cylinder cover.

OIL PRESSURE RELIEF VALVE.

Each engine is equipped with an oil pressure relief valve which is located on the left-hand side of the lower half of the crank case at the rear of the engine, and is nonadjustable. The spring length is made so that the plunger will release the oil at from 50 to 75 pounds per square inch pressure with an oil temperature of 150° F. and crank shaft speed of 1,450 revolutions per minute. Sometimes some foreign substance may get under the valve seat, causing the oil pressure to drop. This can be remedied by removing the valve and cleaning the seat thoroughly. Different oil temperatures will cause the oil pressure to vary, but it will readjust itself when the temperature reaches normal.

CARBURETOR.

The Hispano-Suiza engines are now using the special Stromberg airplane carburetors on the models E and I. In this type of carburetor the fuel is metered and discharged by suction generated from, and depending upon, the rate of air delivery through the Venturi tubes to the carburetor. The fuel delivery is made to respond in proper proportion to this suction by the induction of air into the jet. This keeps the mixture constant throughout the throttle range. The compound Venturi tube construction also develops a powerful suction at the point of fuel discharge, and in conjunction with the air injection gives complete atomization. The float mechanism is positive in its action and hung in such a way that it will operate at angles between 45° climb and a straight dive, as well as under a considerable sidewise inclination. The float needle valve is pointed upward so that any dirt will wash down away from the seat, and is held to its pin by a self-contained spring plunger to obviate wear under the vibration of the engine. The needle-valve point is of an especially hard noncorroding alloy, while the seat is of softer material so that it follows the shape of the harder needle point. The operation of the float mechanism during different aerial maneuvers depends not only upon gravity but also upon the motion of the airplane. Assuming that the carburetor is mounted with the air entrance to the front of the plane, the carburetor float will function normally when the forces are such that the pilot is resting on his seat, leaning hard against the back or sides of the seat, or tending to slide forward. When diving at a steep angle, if the throttle is closed all the way to the idling position, some fuel will drain out of the main discharge jets in the air entrance of the carburetor; this will drain away

through the air horn drain tube when the plane straightens out, but the accumulation will be avoided altogether if the throttle is kept a little farther open so that there is enough draft in the Venturi to carry the fuel up from the jet into the engine. If the position of the plane is such that the pilot tends to fall away from his seat, the same forces will cause the float to go up. This closes the float-needle valve. At the same time the fuel will go to the top of the float chamber and cease to flow from the discharge jets. It will not leak from the vents in the top of the float chamber, however, if the throttle is kept slightly open.

The mixture delivered by this carburetor is subject to little variation in passing from sea level to approximately 3,000 feet altitude. In the " rich " position the mixture is slightly richer than necessary. This can be corrected for more than 20,000 feet altitude by moving the altitude-control lever forward to the " lean " position. The control should always be placed in the position which will give the leanest mixture consistent with the maximum revolutions per minute of the engine. The control of the mixture is obtained by the rotation of the sleeve in the pilot's control, which opens to a greater or less extent, or closes off entirely the communication between the float chamber space and the holes drilled in the upper part of the large Venturi tube. The float chamber has also a smaller atmospheric vent communicating through a gauze strainer with the interior of the air entrance of the carburetor. When the connection to the Venturi is fully open, a considerable suction is communicated to the float chamber and this opposes the suction at the main discharge nozzle, thereby reducing the gasoline flow through the metering nozzle. When the passage between the Venturi and float chamber is shut off entirely atmospheric pressure exists in the float chamber and the maximum gasoline delivery is obtained. With the Venturi suction channel partially opened the gasoline flow is correspondingly reduced. Since a strong suction exists in the float chamber when the control is in the lean position, care should be taken that the joint between the upper and lower halves of the carburetor is kept tight, and that the gasoline-channel plugs in the lower part of the carburetor are drawn tight on their gaskets. If these leak sufficiently to allow gasoline to drip, they will also permit air to be drawn in with the flowing gasoline, which will interfere somewhat with the mixture. Most carburetor troubles arise from the presence of dirt in small particles. The best preventive is to keep the strainer and strainer chamber clean. After 10 hours running, and before every important flight, the strainer should be cleaned and the strainer chamber drained by taking out the plug. If leakage or flooding occurs, a careful inspection should first be made to see whether the leakage is due to some plug below the normal gasoline level of the carburetor being

loose on its gasket, or whether the float valve is insecurely seated, allowing the level to rise so that the gasoline overflows from the main discharge jets. In the latter case the strainer chamber should be inspected and drained to remove any dirt, and carburetor flushed to wash out any particles on the needle-valve seat. It may also help to remove the plug beneath the float valve and with a screw driver rotate the needle valve within the limits permitted, while pressing it up lightly against the seat. If flooding persists, it will be necessary to remove the carburetor from the engine and substitute a new needle valve or seat, or both, as required. See that the float is not punctured and does not contain any gasoline.

On attaching the throttle and altitude-control levers, great care should be used in adjusting them, and that the throttle lever will move through 70° from closed to wide-open position. The lever has a 1⅞-inch radius from the center of the throttle lever stem to the center of the hole in the throttle lever. The altitude adjustment moves through 45° from closed to wide-open position and the lever has a 1⅝-inch radius from center to center. The carburetor is so mounted that all the control connections are made from the rear end of the engine. The installation is such that motion longitudinal to the crank shaft of the engine is required to operate them. Each control should be provided with a ratchet working over a toothed sector to hold it in any desired position. All controls should work freely and at the same time permit a minimum of lost motion.

PROPELLER HUB.

In fitting a hub in a propeller always put the keyway of the hub in the axis of the blades. Cranking the engine is facilitated if the propeller is keyed in this position. Moreover, this is of vital importance, since this position has been adopted for adjustment of the layout for firing the machine gun between the propeller blades. The mounting of the hub on the taper of the crank shaft requires very particular care. The hub supplied with each engine has been fitted to its taper by lapping with emery and oil. The hub and crank shaft taper are then thoroughly cleaned and the key replaced, making sure the hub and taper are well lubricated. This operation should be repeated each time a new hub or one that shows wear is placed on the crank shaft, always remembering that a bad fit rapidly develops play and if run in this condition may do great damage. The type of hub used on the Hispano-Suiza is of the self-pulling type, and is applied in the following manner: There is one inner propeller hub nut, and one outer hub nut holding the hub on the crank shaft, both held together with a lock wire. To fasten the hub on the crank-shaft taper, insert the inner nut in the outer nut, so that both have

their hexagon heads toward the same end. The thread on the outside of the outer nut fits the thread on the inside of the hub. Screw the nut into the hub while the inner nut is still in the outer nut. This can be screwed all the way in until it bottoms and should be then backed off about three or four threads. Place the hub on the crank-shaft taper and start the inner nut on the thread of the crank shaft by the aid of a special wrench, which is supplied with the tool equipment. Pull the nut home. This will draw the hub on the crank-shaft taper. After the hub is drawn up the inner nut is locked in place by drawing up the outer nut and the nuts then locked together by the lock spring wire.

MACHINE-GUN MECHANISM.

The machine-gun firing mechanism or interrupter driving mechanism is driven from either the left or right lower vertical shaft by a gear which is pinned to the lower vertical shaft gear. The interrupter shaft is mounted on two ball bearings and is driven at crank-shaft speed. The synchronizing of the interrupter with the propeller is facilitated by the double-flange connection which bolts it to the driving shaft. One flange has one less bolt hole than the other. The firing mechanism should be set so that the bullet would just miss the trailing edge of the propeller by about half an inch (if gun were loaded) when the engine is turned over by hand. Test synchronization by cocking the gun and turning the engine over by hand, stopping when firing hammer clicks. Sight down the gun to see if the trailing edge of the propeller has passed the end of the gun. This should not pass the gun by less than one-half an inch or more than 2 inches.

PERIODICAL INSPECTION.

At the expiration of about fifty (50) hours of running time the engine should be taken from the fuselage and given a thorough inspection. Fifty hours is about the average time a motor is used before it is taken down for inspection, although some motors have been kept in service considerably longer. No doubt the motors would run an unlimited number of hours, but experience shows the 50-hour period to be best. The motor is taken down more for inspection than actual overhauling work. Valve troubles are probably the most common with an airplane motor. This is due largely to the fact that the valves are subjected to such great heat at all times, and unless the valves are made of the best grade of steel they are very apt to warp, and by so doing will be held off of their seats. Once this occurs, the valves will be burned by the escaping exhaust gases.

Another important point of the disassembly is the cleaning out of oil passages, such as the cam shaft and the hollow crank shaft. These often become clogged and can not be cleaned unless the engine is completely disassembled. Small particles of bearings and other foreign material will lodge in the channels, thereby affecting the oil pressure, and possibly cause the burning out of a bearing. These troubles are nearly all avoided by periodical inspection, cleaning, and adjustment.

REMOVAL OF ENGINE.

To remove the engine from the plane, proceed in the following manner: Take off the propeller and hub assembly. Drain the water from the radiator and engine by removing the drain plug in the lower half of the water pump. In most cases it is necessary to remove the radiator before lifting the engine. Be sure that all connecting members are removed, such as tachometer shaft, gun-firing attachments, carburetor control rods, gasoline air pump line, oil and water connections, magneto wires, etc. Be sure that all of the oil is drained from the sump. If a gun is mounted over the engine, it should be removed before proceeding to remove the engine. Remove the engine bolts and lift out the motor. See that the slings which are used to lift the engine do not put any strain where it will do damage. Bolt the engine to a suitable stand. Proceed with the disassembly as outlined in the manual for this engine.

CHAPTER 3.

OVERHAULING THE HISPANO-SUIZA MOTOR, MODELS I AND E.

BRIEF SURVEY OF MOTOR.

Before starting the overhaul of a new motor it is necessary to examine the motor as a whole before commencing work; so is it with the Hispano-Suiza engine. Especially is it important to look over the entire motor carefully to become familiar with the design and general construction. A brief examination in this way will indicate that the following method of procedure should be adopted.

WHERE TO START THE DISASSEMBLY.

After the mechanic has assured himself that the motor is securely fastened to a suitable stand (one which will revolve if possible), he should commence work by removing the carburetor and manifold as one unit. In order to do this, loosen the four flange nuts on the end of the T manifold, also back off the union nut of the detachable flange inlet pipe. It is not necessary to take the nuts completely off; shaking the unit from side to side will sufficiently loosen it so that it may be removed. In doing so, care should be taken not to destroy the gaskets. Now the nuts may be removed and the manifold taken off. The nuts should be replaced on the studs to prevent the threads being injured in the subsequent handling of the cylinder block on the bench.

REMOVAL OF SPARK PLUGS.

Take out all spark plugs and disassemble each to be cleaned. After all carbon is removed and the porcelains examined for possible cracks, plugs should be reassembled and the spark gaps adjusted to 0.021 of an inch. The plugs should now be laid aside carefully, so that the adjustment of the electrodes will not be changed by rough handling. The removal of the spark plugs at this time relieves the compression in the cylinders and makes it possible to turn the motor freely for various checking operations.

MOUNTING THE TIMING DISK AND SCALE.

The dead-center indicator should now be screwed into the spark-plug bushing of No. 1 left cylinder, and at this point it would be

well to notice that the cylinder blocks are designed right and left from the gear end of the motor, and are numbered from the propeller end, 1, 2, 3, 4 right, and similarly left. The timing scale may now be placed on the engine, the center of the scale lining up with the center of V of the engine. The scale is attached to and held by the tops of the two studs which are nearest to the propeller hub and which hold the lower half of the crank case in position. In order to place the timing disk, the propeller hub must be removed. There are two classes of propeller hubs; one class has a double nut and the other class a single nut. The process of removing each class of hub is as follows:

Removing the single-nut hub. First remove the lock and select a spanner wrench that fits the nut. Turn the nut steadily and slowly left-hand and the hub will be slowly drawn off. This is by reason of the fact that the nut is a differential nut, the larger diameter thread being nine turns to the centimeter as against five turns to the centimeter on the smaller diameter thread, with the result that the hub is withdrawn from the shaft before the nut can unscrew from the hub.

Removing the double-nut hub. Two nuts will be noted at the end of the hub, both of the hexagon type with a spring wire lock between them. First remove the wire lock, then place a wrench over the larger nut, unscrew it two turns to the left. Fit a wrench to the smaller nut and start turning it off left-hand, watching the larger nut, as it has a tendency to turn. If it should display a tendency to turn hold it with a wrench and continue to back the smaller nut off until the hub is loosened.

After removal of the hub the special hub with the timing disk attached can be fastened to the crank shaft. The four slotted holes in the disk are to allow the disk to be moved, either forward or backward, to make the top center of the No. 1 cylinder correspond with the zero mark on the timing scale. This is best accomplished by reciprocating the piston so that the indicator will register the highest point of travel. At this point the line marked "Top Center, 1 and 4, left" should correspond with the zero line on the scale. Then, by rotating the motor in a counter-clockwise direction a quarter turn the top center line of Nos. 1 and 4, right, should correspond with the zero line on the timing scale. The top center indicator may now be removed, as its purpose has been fulfilled.

REMOVAL AND INSPECTION OF TACHOMETER DRIVE.

The tachometer drive coupling must now be removed and inspected carefully for wear. When assembled this unit should have one

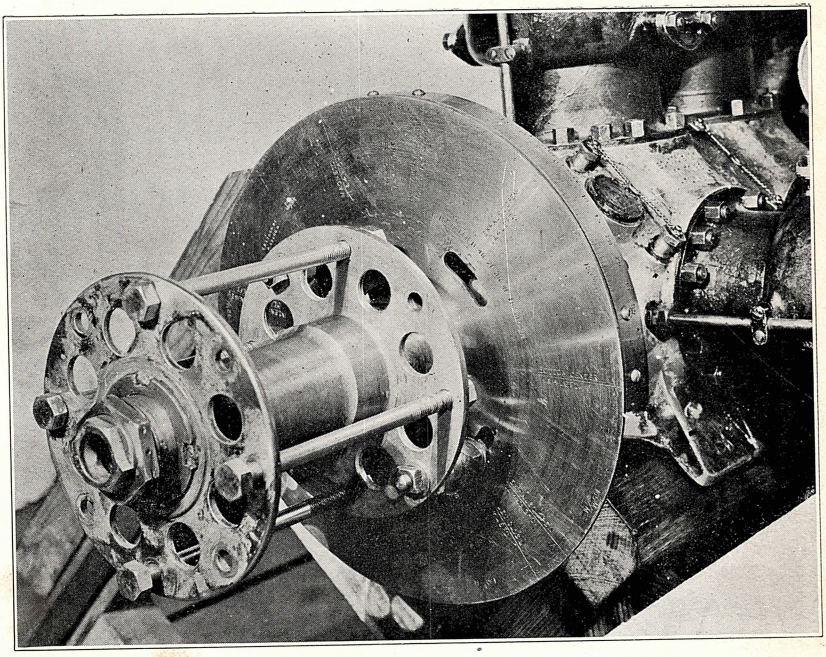


FIG. 1.

thirty-second of an inch end play. The end play should be tested at several different points during one revolution, for the shaft may bind, due to misalignment, although the swivel may be perfectly free before being assembled to the engine. If this trouble is indicated it may be sometimes rectified by setting the swivel half a turn from the original position. If this method is unsuccessful a heavy washer should be placed under the tachometer housing where it screws into the cylinder cover. The clearance between the swivel and the shaft should be at least 0.0032 of an inch. The tongue clearance of the swivel should be 0.020 of an inch.

REMOVAL OF AIR PUMP.

Unscrew the air pump from the cylinder cover, or cam-shaft housing, with a suitable spanner wrench, inserting it in the four intake holes around the base of the pump. Take the pump apart, inspect the valve seat and stem for wear. The check valve must seat fully and hold air pressure. The stroke of the plunger must not be less than seven-sixteenths of an inch, and the union at the top of the pump must fit tight. The joint where the pump is taken apart for inspection must also be air-tight, a fiber gasket being used at this point. The plunger clearance in the guide should be 0.001 of an inch. The clearance of the guiding stem for the check valve should never be more than 0.012 of an inch nor less than 0.002 of an inch. After careful inspection of the pump it may be reassembled and screwed to the cam-shaft housing, using the same method as in removing.

REMOVING CAM-SHAFT HOUSINGS.

Cam-shaft housings should next be removed by taking out the screws at the edge of the housing and cleaned thoroughly. Be especially careful of the bottom edge, as it has been ground to insure a perfect fit to prevent leakage of oil.

DETERMINING DIRECTION OF ROTATION AND FIRING ORDER.

The direction of rotation of the engine may be determined, if not already known, by watching the successive operation of the valves, and remembering that the direction of rotation is designed from the gear end of the motor. The firing order should now be checked by watching the successive operation of the valves, beginning with No. 1 left cylinder. The firing order will be found to be 1 left, 4 right, 2 left, 3 right, 4 left, 1 right, 3 left, 2 right.

CHECKING THE IGNITION WIRING.

Next, trace out the high-tension wiring, making note of the alphabetical manner in which the wires are designated. All wires leading from the right-hand magneto, gear end, lead to the plugs on the inside of the V and are lettered: A to 1 L, B to 4 R, C to 2 L, D to 3 R, E to 4 L, F to 1 R, G to 3 L, H to 2 R. Correspondingly, the wires leading from the left-hand magneto lead to the plugs on the outside of the engine and are lettered: H to 1 L, G to 4 R, F to 2 L, E to 3 R, D to 4 L, C to 1 R, B to 3 L, A to 2 R. Place No. 1 left cylinder on firing position and note which is No. 1 segment on the distributor blocks of both magnetos. It should be observed that the rotation of the right-hand magneto is counter-clockwise from gear end, and for the left-hand, clockwise; also, that the magnetos run at engine speed. The high-tension wires may now be removed, examining each carefully for faulty insulation and loose terminals caused by broken strands or imperfect soldering. It is convenient at this point to check the clearance of breaker points of the magnetos. When fully separated, this clearance should be 0.020 of an inch. A gauge of the proper thickness is attached to the magneto wrench.

CHECKING MAGNETO TIMING.

Before removing the magnetos the timing should be checked, each one individually. Place a cigarette paper between the breaker points, turning the motor in the direction of proper rotation until the compression stroke of No. 1 cylinder commences. The breaker points of both magnetos should separate at 20° 20′ before top center for model I or 25° before top center for model E. These degree points are obtained by noting that the line marked "Top Center 1 and 4, left" is opposite the 20° 20′ or 25°, as the case may be, on the scale. The magnetos and their couplings may now be lifted off by loosening the eight cap screws that fasten into the base of the magnetos, and by removing the two large cotter pins that extend through the adjustable couplings. Removal of the magnetos is made easier by sliding the couplings slightly toward the magnetos, thereby releasing the coupling from the driving end. The magnetos must be raised high enough to clear the dowel pins in the base, but under no circumstance must they be pried upward with any tool, for both the base plates and the bases of the magnetos have been ground to insure a perfect fit and alignment without the use of any shims. 0.001 of an inch has been left around the pins.

ASCERTAINING THE VALVE TIMING.

Attention should next be given to the valves and cam shafts. The clearance between the back of the cams and the valve tappets should

be 2 millimeters, or 0.978 of an inch. The clearance should be checked on each valve by a gauge supplied with each tool kit. The valve timing of each cylinder must now be checked individually, the correct setting being an important feature of this engine. The proper timing is as follows: Intake opens 10° after top center, intake closes 50° after bottom center, exhaust opens 45° before bottom center, exhaust closes 10° after top center. Notation of all openings and closings should now be made in order that any irregularities may be rectified in reassembly. The exact point at which the valves open and close may be conveniently determined by the use of a cigarette paper in the clearance space.

REMOVING AND EXAMINING CAM SHAFTS AND BEARINGS.

In removing the cam shafts, the nuts retaining the two end bearings should be removed first, so that the springs of the valves will not tend to spring the shaft or bearings. The middle bearing nuts may now be loosened at the same time, guiding the shaft, so that both ends will be lifted evenly. If this method is followed, no force will be required. Screw the nuts back on their respective studs to protect the threads and prevent losing the nuts. Remove the bearings opposite the gear end and mark them "left" or "right" as the case may be. This is important, for the bottom surfaces of these bearings have been fitted to the top of the cylinders in order to convey the oil from the channel through the cylinder casting to the hollow cam shaft. If there is a poor fit at this point, and the bottom of the bearing is not oil-tight, the oil pressure will be seriously interfered with. The center bearings should next be removed and marked in the same manner. Remove the hexagon nuts on the gear end of the cam shaft and pull off the gear, noting during its removal into which of five keyways the single Woodruff key is inserted, for to replace this key in the wrong keyway will cause unnecessary trouble in retiming the motor. Next, take off the last bearing and mark it "left" or "right." The cam shafts and all bearings should now be carefully cleaned preparatory to refitting, removing, however, the wire locking ring and metal disk in the front end of the cam shafts. This is essential, for dirt sometimes will lodge against the disk and can not be properly cleaned by flushing through the oil holes. After cleaning, the disk should be replaced. The cam-shaft bearings have been "line reamed" and should have a maximum of 0.004 of an inch clearance and a minimum of 0.002 of an inch. The end play of the shaft is taken care of by the rear bearing (gear end). The boss on the back of the cam-shaft gear makes running contact with the one surface of the rear bearing, while the rear face of the exhaust cam of No. 4 cylinder makes running contact with the other surface. The total

end play in this latter instance should be 0.020 of an inch. The end play between No. 1 exhaust cam and the front bearing should be 0.025 of an inch, but never less than 0.010 of an inch. The oil hole in the front end of the came shaft must register with the oil hole in the cam-shaft bearing. Also, the hole in the flange must register with the hole in the cylinder jacket. Before putting aside the cam shaft the nose of the cams should be inspected for excessive wear. The Woodruff keys should not fit too tight, as it is frequently necessary to change them to alter the timing. Properly, these keys should have about 0.0007 of an inch clearance in the cam-shaft gear and about 0.00025 of an inch in the keyway of the cam shaft. The clearance between the cam-shaft gear and the cam shaft should be about 0.00025 of an inch. This gear should not be tighter than the above, as it must be removed frequently, and a clearance of 0.009 of an inch should be left above the key.

REMOVING MAGNETO SUPPORTS, GEAR HOUSING, ETC.

Remove the breather pipe by turning it to the left. If found to be extremely tight, a snubbing device made of a stick of wood and a leather strap should be used. This may be laid aside after noting that check valve in the bottom is loose and free to operate. The magneto supports should be removed next, in order to make the cylinder-stud nuts and the four-flange nuts of the packing box around the vertical shafts more accessible. The removal of seven nuts should be all that is necessary to remove a magneto support unless the spline on the end of the small shaft is too tight. Replace the seven nuts and lock washers in order to protect the threads. On the magneto support is an auxiliary oil pump which should be removed. Remove the cover that houses the gear and inspect the interior of the housing. If the gears have been out of line they will start cutting the housing, but when properly aligned there should be a minimum clearance of 0.002 of an inch between the teeth and the pump housing. The shaft of the drive gear should have 0.0025 of an inch clearance. The clearance between the tips of the teeth and the housing should be about 0.002 of an inch. After the desired clearances have been attained, replace gears and cover, making sure that the latter is perfectly clean before screwing down. The cover screws should be safetied by threading a soft wire through the heads of the screws.

REMOVING THE MAGNETO-DRIVE ASSEMBLY.

The magneto support and its various parts after removal should be inspected. Take out the main shaft, which is mounted in the center, by driving with a rawhide hammer. Then thoroughly clean the

shaft and magneto support. Do not, under any circumstances, use a scraper on the surface where the magnetos are fitted, as this surface has been ground to insure perfect alignment. The coupling gears must be concentric with each other within 0.002 of an inch. They should be tested with a micro-dial indicator if one is available. Also, the face of the coupling near the circumference should be tested to see that the flange does not "wobble." With both magnetos mounted on the support, revolve the armatures to see that they are free during a complete revolution. A clearance of about 0.020 of an inch should always be maintained between the teeth of the spiral gears at the center of the support. The magneto-drive shaft ball bearings should fit in the casing with a clearance of 0.0005 of an inch, with a maximum of 0.001 of an inch allowed. The bearing on the end of this shaft should fit in a casing with a clearance of 0.0005 of an inch, and the shaft should drive into this with a light tapping fit. This bearing is held on the shaft by a large hexagon nut which in turn drives the gear-type oil pump. The clearance of the shaft which enters this nut should be great enough to allow for misalignment.

REMOVAL AND INSPECTION OF WATER PUMP.

At this point in the disassembly all oil should be drained from the crank case. Then take off the two pieces of hose connecting the water pump with the lower portion of the cylinders, taking care not to bend the hose, thereby destroying its inner lining. To avoid doing this, unscrew the two nuts that hold the water pump to the bracket, also the filister head screw which locks the packing nut union, and lower the complete water pump. Replace the two nuts on the studs. With the fingers try the impeller, which should spin very easily. This, which is made integral with the shaft, is the only moving part. Remove the front cover, examine the interior and impeller for wear. Notice the thrust bearing, which is merely a button placed directly under the center of the shaft. When the pump is properly assembled with a paper gasket under the cover, the shaft should have an end play of 0.005 to 0.007 of an inch. The packing nut should not be screwed down so tight, after repacking, that the shaft can not be still turned with the fingers. The pump-shaft bushing should be 0.003 of an inch larger than the pump body to allow for a driving fit. The pump shaft must have at least 0.002 of an inch clearance in the bushing. The following clearances should be maintained as nearly as possible: Between impeller and casting, 0.040 of an inch at bottom and 0.30 of an inch at top; thrust bearing should be 0.002 of an inch oversize; the pump-shaft cover should be about 0.003 of an inch loose in the pump body. In reassembling, no shellac or other liquid is used on the paper gasket, as both surfaces of the joint have been ground.

REMOVING THE CYLINDER BLOCKS.

Before removing the cylinder blocks loosen the oil nipple pack nuts at front end of the cylinders and the gear-housing packing nuts at the rear. Then remove all cylinder stud nuts, using the special wrenches provided. It is advisable to allow one nut to remain on the upper side of each cylinder block until everything is in readiness, so that it will not fall over. Turn the crank shaft so that the pistons, Nos. 1 and 4 left, are on top center; take off the remaining nut and lift the block away from the crank case. Take care to lift evenly, so as not to bind the pistons and strain the connecting rods. Also make sure that the pistons are supported after leaving the cylinder blocks so that they will not fall over against the case.

REMOVING THE PISTONS.

After the other block has been removed in the same manner, the pistons should be removed immediately to prevent them from receiving any injury. Piston pins, which in the models E and I are of the floating type, should be an easy driving fit in the piston when the latter is cold. The retaining ring, which has a clearance of from 0.001 to 0.003 of an inch in its slot, should be loosened by expanding with the fingers so that it may be slid down the piston sufficiently to allow the piston pins to be removed. In driving loose the piston pins be sure and back up the connecting rod with sufficient weight to prevent straining it. As the pistons are removed they should be placed in a suitable box with divisions and should be so marked that they will be replaced in the same position they originally occupied.

REMOVING THE RINGS AND CHECKING THE PISTONS.

The rings should be removed from the pistons one at a time and after cleaning replaced in exactly the same position as formerly. In removing the rings use only the fingers to expand them and exert great care in avoiding scoring of the pistons with the sharp edges of the rings. Where there are two rings in one slot, the top ring should be replaced on top, and neither ring should be turned upside down. In cleaning carbon from the pistons a soft scraper should be used in order not to scratch or otherwise mar the soft aluminum. Particular attention must be paid to the removal of all carbon from the inside of the piston, as an accumulation here fouls the oil system. After rings are replaced in the same manner as they were removed, the end clearance should be 0.12 of an inch. The side clearance in the slot should be 0.002 to 0.003 of an inch for the upper ring and about

0.001 of an inch for the other rings. At this point, after properly cleaning the cylinder blocks, the clearance between piston and their respective cylinders may be checked. This should be 0.040 of an inch at the head of the piston, tapering down to 0.014 of an inch at the skirt. A variation of 0.003 of an inch either way is allowed at the head. The clearance between the piston pin and the connecting rod should be 0.0002 of an inch, and the end play of the connecting rod at the position pin should be three thirty-seconds of an inch. Before finishing with the pistons, the last and a very important feature is their weight, which should not vary more than a half an ounce between different pistons. A greater variation in weight than this will cause excessive vibration in the engine.

REMOVING AND EXAMINING VALVES AND WEIGHING SPRINGS.

In removing the valves, first place some blocks of wood inside the cylinder for support, for unless this is done the valves will drop into the interior of the cylinder. Next place the hollow yoke of the lifter on the top of the valve-tappet washer and unscrew the valve tappet until the springs are no longer compressed. Then remove the valve lifter. Continue until the springs are released from all valves. Remove the blocks of wood, after laying the cylinder block on its side, and take out the valves, placing them in such a way that they will be returned to the same cylinders from which they were taken. In removing the valves, and in all subsequent handling of the valves inside the cylinders, take care that the edges do not nick the interior of the cylinder walls. Examine all valves carefully for any signs of leakage, not omitting the exhause-valve stems which may be warped with excessive heating. Inlet-valve stem clearance should not exceed 0.0058 of an inch; otherwise air would leak down around the stem and rarefy the mixture. The exhaust-valve seat is 45° and the total lift of each valve is three-eighths of an inch. All valve springs should be tested for uniformity of weight and should weigh as follows: Inlet and exhaust outer springs, 45 pounds when compressed to $1\frac{37}{64}$ inches. Exhaust and inlet inner springs, 35 pounds when compressed to $1\frac{27}{64}$ inches. After the valves have been properly cleaned, the springs weighed and cleaned, they should be assembled on the cylinders and held there by the flat-headed adjusting screws while the cylinders are being cleaned and inspected. This step will keep the valves and springs together until ready for regrinding.

REMOVING AND INSPECTING THE VERTICAL DRIVE SHAFTS.

Before grinding, however, it is well to remove and inspect the vertical shaft at the end of each cylinder block. Take out the wire

locking ring that prevents the steel tubular housing from turning and unscrew this housing with a suitable spanner wrench. It should be noted that the small indentation in the vertical shaft bushing (where the locking ring bottoms) is not drilled through the bushing, as the oil would be allowed to leak out. The vertical shaft and bushing can now be driven out with a piece of wood and a hammer. The clearance of this bushing should be from 0.005 to 0.0015 of an inch, thus allowing the shaft to be driven out quite easily, which is often necessary during required changes in timing. The shaft should be cleaned and the fit of the spindle at the lower end checked up. The ring shrunk onto the shaft just under the gear is to take up the thrust. There should be an end clearance of 0.005 of an inch between the bushing and the ring. The vertical shaft should have a clearance of 0.002 of an inch inside the bushing, and the spline where it enters the vertical shaft packing-box union, the packing therein preventing oil leakage. All cylinder walls should now be thoroughly cleaned and polished and carefully examined for signs of scoring. If found to be O. K., the vertical shafts may be replaced and the work of refitting the valves taken up.

GRINDING VALVES.

Unless it is certain that all valves need regrinding, they should first be tested by placing gasoline inside the combustion chamber, with the blocks upside down, and watching to see if it will seep through. If there is no leakage, the valves should not be ground. If there is leakage, they should be ground as little as possible. Do not use a new valve when an old valve can be reground to a satisfactory fit, for the old valves have been subjected to excessive heat and all strains in the steel have been removed; hence when this valve is properly fitted it will continue to keep its seat. In grinding the valves short strokes must be used and the valve must be lifted from the seat after each stroke. Little pressure is needed, but the grinding compound should be frequently renewed. After a proper seat has been acquired the greatest care must be exercised in washing the grinding compound away from the valve and valve seat. When all valves are properly ground they should be reassembled with their springs and locking nuts. Before laying the cylinder blocks aside as completed one more test should be made. This is to make sure that the bottom flanges of the cylinder block have not been distorted. This may be done with a surface plate or with the use of an accurate straightedge. If the flanges are not true, the oil will leak out and the cylinder block can not be used until repaired.

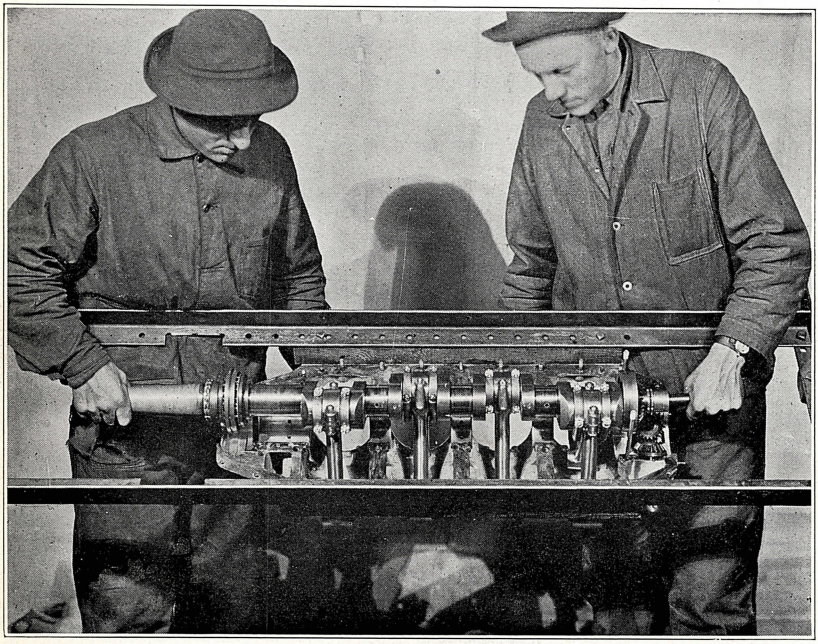


FIG. 2.

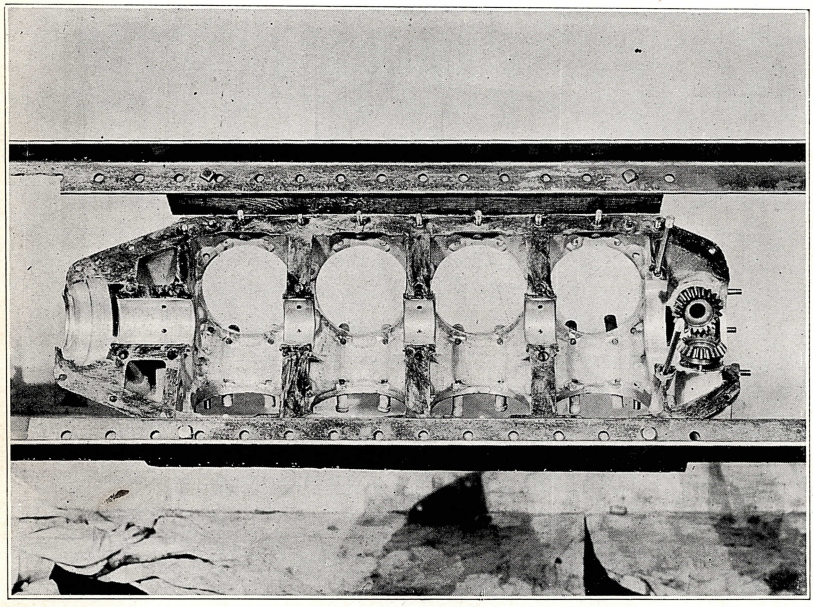


FIG. 3.

PREPARING FOR REMOVAL OF CRANK SHAFT.

The crank shaft is now ready for removal with the exception of the timing disk, which must first be taken off. Cut the wires locking the main-bearing stud nuts and remove the nuts, noting the difference in the two nuts on the studs nearest to the propeller end. The hexagon head is at the top of a shank of suitable length to allow the use of an open-end wrench, but a socket wrench is preferable. If there is now no oil in the crank case, it can be turned over, bringing the motor upside down. Before revolving the stand, however, do not neglect to make sure the bolts holding the motor to the stand are in place. Take off the oil-pressure relief valve body, and then remove the oil-pressure valve plunger and the small helical spring that is centered in the plunger. It will be noticed that this type of valve is nonadjustable, the spring length being such that the plunger will release the oil at the pressure of from 50 to 75 pounds and with a crank-shaft speed of 1,450 revolutions per minute. It is important that no foreign matter of any kind should lodge on the valve seat of this pump, as it will immediately cause the oil pressure to drop. Next remove the connection leading to the oil-pressure gauge and to the oil tank; then remove the sump or drain plug, noticing the screen fastened over the plug to strain the oil before passing though the gear pump. Also remove the plug at the front of the crank case to allow for subsequent flushing of the oil pipe line when cleaning the crank case. Now that these small parts are disposed of, remove all crank-case stud nuts and the six bolts along the parting line of the crank case. Also remove the two stud nuts near the oil pump. The lower half of the crank case may now be removed, but under no circumstances must any instrument be placed between the halves to pry them apart, as both are ground to an oil-tight fit without the use of any gaskets.

REMOVING THE CRANK SHAFT AND INSPECTING THE CRANK CASE.

The crank shaft may now be removed and placed on a special crank-shaft stand. Next take out the oil-pump drive gear, which should have a clearance of 0.002 of an inch in the bushing, the bushing being held in place by a cap screw. Drive out the cast-iron oil-pump body by inserting a suitable punch of soft material between the webbings of the crank case and on top of the pump body and tapping lightly with a hammer. This pump body should not be fitted tighter than half a thousandth inch and should drive out easily. The lower half of the crank case is now ready for thorough cleaning, paying special attetion to the proper flushing out of the oil pipe, cast integral with the case, and the oil holes in the center of the main

bearings. Inspect the whole case carefully for cracks. Examine the casting where the oil-pump body is located and become familiar with construction of this part.

CLEANING AND INSPECTING THE OIL PUMP IN CRANK CASE.

Next clean the oil-pump assembly. The pump shaft is never fitted with a clearance of less than 0.001 nor more than 0.0024 of an inch at the top, and never more than 0.003 of an inch at the bottom. The bottom of the pump shaft should turn freely by hand when fitted into the bottom bushing, the clearance being about 0.002 of an inch. Both halves of the glands or vanes are alike in size and are interchangeable, and are forced against the body of the pump by two small helical springs of equal tension. Both halves should be evenly spaced between the walls of the pump and should have an end clearance of from 0.002 to 0.005 of an inch when the shaft end vanes are held against their end bearings in either direction. The end play of the shaft between end bearings should be hardly perceptible with the hands when the halves are held together without a gasket between them. After the paper gasket is put in place and the ends clamped together by the bolts, the end play should be from 0.004 to 0.006 of an inch. When placing the paper gasket between the bracket and the oil-pump body, be sure to put a hole in the gasket, so that the oil leaking by the shaft into the oil pocket can be sucked back into the oil pump. After putting the pump driving pinion in place, see if the pump and pinion can be turned by hand. The exhaust ports on one side of the pump must register with the ports in the crank case leading to the oil-pipe manifold. The intake ports on the other side must drain oil from one of the holes cored through the rear of the crank case and having a plug screwed into it. In replacing the pump body it will be noticed that the bolts are so spaced that the pump can not be incorrectly replaced. It is necessary that the joints between the pump body and bracket be oil-tight. Note the spiral oil groove in the bottom of the pump shaft which prevents the oil from running down the shaft. The oil filter should be taken apart by removing the small cotter pin and unscrewing the screen. Clean the screen inside and out and after cleaning reassemble and safety with a cotter pin. The filter should be taken out and cleaned every ten (10) hours of engine operation. The crank case is so designed that when the oil filter is screwed into the case it will necessitate the oil entering the filter through the eight holes at the base of the screen when passing upward through the screen and through the oil manifold.

REMOVING THE CONNECTING RODS.

Make a thorough examination of the connecting rods, noting that the rods with the smaller bronze boxes at the lower ends go on the

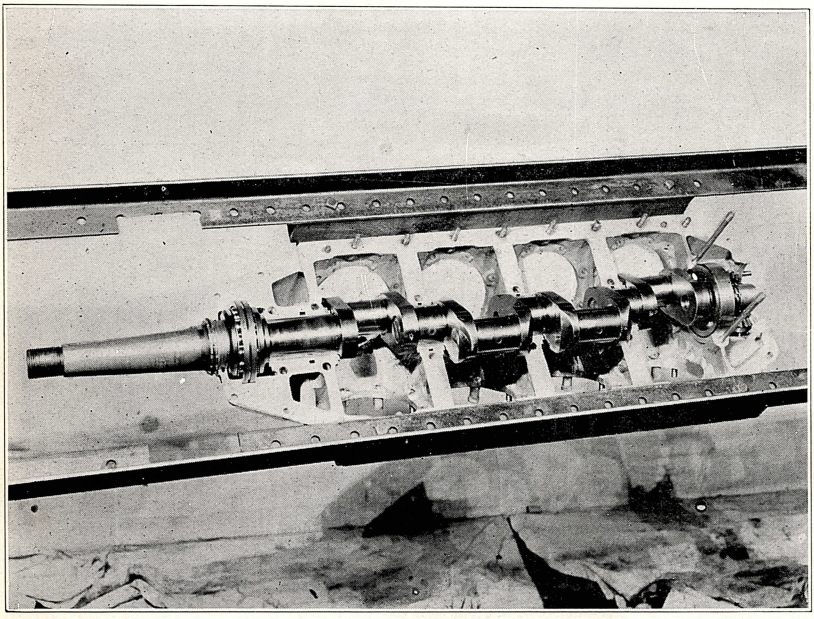


FIG. 4.

left side of the motor, and the rods with the outer bearings go on the right side, as one faces to the front. Also, the numbers on the connecting rods always are toward the front. The conecting-rod bolts and nuts are all numbered to correspond with the conecting-rod bearings from which they were taken. The nuts have punch marks indicating how much the nuts should be tightened on their studs. Each nut should be drawn up so the punch mark lines up with a similar mark on the stud. If proper nuts and studs are used on the proper connecting rods this will prevent the bearings from ever being drawn up too tight. In taking the connecting rods down, the outer one is removed first, and the cap and nuts replaced, so that they may not become mixed up. Notice the holes on the inner connecting-rod bronze bushing for lubricating the other one. The inner rods are removed in the same manner.

THE MAIN BEARING SHELLS.

The main bearing linings in the lower half of the crank case are held in position by dowel pins screwed into the case. These pins make it unnecessary to secure the upper half. The linings should be forced into the crank case by light tapping with a block of hardwood. A proper fit should be secured by the use of bluing and a scraper. It should be noted that the main bearings have three holes spaced equally around the circumference, the holes conducting oil from a channel which is cut into the crank case, and supplying oil to the bearings from each side.

CLEANING THE UPPER HALF OF CRANK CASE.

The upper half of the crank case should now be removed from the stand and cleaned, care being taken of the lower surface. Following the cleaning, inspect the gears at the end. These vertical shaft-drive gears must have at least 0.010 of an inch clearance between the flange on the bushing and the rear surface of the gear. The shaft should have 0.002 of an inch in the bushing.

CLEANING AND ADJUSTING THE THRUST BEARING OF THE CRANK SHAFT.

Examine the crank shaft and thoroughly clean it inside and out. Inspect the thrust bearing and the propeller thrust bearing nut, which also adjusts the play. It should be tight enough so there is no perceptible play, yet the middle race must spin when slapped with the palm of the hand. As the thrust bearing locates the crank shaft longitudinally, try the shaft in place before permanently locking this nut. The clearance between the faces of the crank arms and the main bearings should be 0.035 to 0.040 of an inch. If the crank shaft

lays too far one way, remove the thrust bearing and turn it around so that the front is toward the rear, and see if any better result is obtained. Again, try turning the middle race around. If a new thrust bearing is installed, a new hole for the locking wire must be drilled with a No. 39 drill. The hole should be a quarter inch deep. After locking the nut make a punch mark in the shaft at the edge of the threads to indicate the location of the hole just drilled. When the crank case is bolted together there should be a clearance of from 0.002 to 0.010 of an inch around the shaft at the propeller end. The thrust bearing should be a push fit on the crank shaft (0.001 inch). The ball bearing on the rear end of the crank shaft must be a light drive fit and have a 0.0005 to 0.001 of an inch clearance when the halves of the case are assembled.

CHAPTER 4.

THE ASSEMBLY.

INTRODUCTORY.

It is assumed that during the disassembly operation all parts have been thoroughly examined and the defects noted. Also, that where parts were found defective, new parts were ordered in their place. During the assembly, work will be done on the assumption that all parts are either new or good enough to put back into the engine. Before all parts are assembled they must be thoroughly cleaned, and as each part is assembled it must be oiled with clean, new oil.

FITTING NEW CRANK SHAFT BEARINGS.

The main bearings of this motor are the bronze-backed babbitt-lined type, split in half at their centers, and nonadjustable. The bearings are held in place by a slight driving fit into their boxes. They are nonadjustable, due to the fact that one half is held in the upper crank case and the other half in the lower crank case. They are not the capped type bearing. When fitting new bearings use the following procedure: Blue the bearing boxes in one-half the crank case where the bearings are to fit. Insert each bearing in its proper place. To do so it will require a slight tapping with a block of hardwood shaped to fit the bearing. After each bearing has been inserted and tapped in place, remove separately and notice the markings from the blue. Where high spots are seen on either the case or the bearing they must be hand scraped so as to insure a perfect fit. After the high spots are scraped down, reblue the case and insert the bearings again to get a better marking. Then remove the bearings, noticing the bluing again and continue the operation until a perfect bearing is obtained.

CHECKING THE BEARING FIT AND MATING CRANK-CASE HALVES.

After the bearings are fitted in one half the crank case so that their backs fit the crank case perfectly, set this half aside and fit the

bearings in the other half in the same manner. After both half shells of the bearings are fitted to both crank-case halves, it may be noticed that the edges of some of the shells project above the mating surface of the crank case. In others, it may be noticed that they are slightly lower. If one half shell projects above the surface, then examine its mating half in the other half crank case. If both half shells project above their respective case surfaces, then it is permissible to file down the half shells until each projects about 0.001 of an inch above the surface. If both half shells of one bearing are below the surface, this bearing must be discarded. In the event one half is above and the other half below the surface, a fit may be obtained, but if new bearings are available it is better to replace such a bearing. After all bearings have been mated and are projecting above the crank-case surface about 0.001 of an inch, then blue the surface of the lower half crank case, making sure the surface has a perfect coating and that the edges of the bearing projecting above the surface also are blued. Then bolt the two half crank cases together. Place all the bolts in their proper places, pulling them down evenly, the same as would be done if the motor were being assembled. Again take the cases apart, being careful not to mar the bluing. Note the markings of the bluing on the clean half of the case. This bluing must be marked on the edges of the bearing halves and also on the surface of the crank case directly opposite the bearing, that is, the crank-case bearing web surfaces must have an even bluing. If the bearing edges are marked and the crank-case bearing web is clean, it will indicate that the bearing edges are projecting too far above the surface and are holding the crank-case halves apart. If the crank-case bearing webs show an even bluing, and the bearings (or bearing) show no bluing on their edges, they are badly fitted and must be discarded. A perfect fit is obtained when the bearing halves show an even bluing and the crank-case bearing webs also show the same. When the bearings are fitted to the case, bolt the case together, cleaning the case before doing so.

REAMING THE BEARINGS AND FITTING END-PLAY CLEARANCE.

The bearings are now ready to be reamed, if a line reamer is available that will ream them 0.002 of an inch larger than the crank-shaft journals. After the bearings have been reamed, separate the cases, and lay the crank shaft in one half of the crank case at a time. Take note of the end clearance of the crank shaft. This clearance must be from 0.035 to 0.040 of an inch between the faces of the crank arms and the ends of the main bearings on both sides of the bearings. Move the shaft one way or the other until the shaft is in the center

of the end play and then measure the clearance. If found to be too little, the sides of the main bearings will have to be hand-scraped until proper clearance is obtained. When proper clearance is found remove the crank shaft and place a light coating of Prussian blue upon the main-bearing journals, replace the shafts in the crank case half and turn the shaft so as to mark the bearings. The bearings must be well marked from the shaft; that is, they should have at least 75 per cent bearing in the center. If a good line reamer has been used and the job done carefully, the bearings should show up with a good marking, but here and there a few high spots may be noticed. These will have to be lightly hand-scraped until removed. Care should be taken not to remove too much metal, as the clearance wanted on the crank-shaft bearings is 0.002 of an inch, and if a 0.002-inch oversized reamer has been used excessive hand-scraping afterwards will create entirely too much clearance. When line-reaming bearings, the reamer will cause a sharp edge to form at the bearing fillets, giving a false end clearance impression, which must be hand-scraped, so the bearing fillets will correspond to the fillets on the crank shaft.

FITTING BEARINGS WITHOUT A REAMER.

When a line reamer is not available this procedure may be used. Incidentally, the only means of regulating the amount of hand-scraping to be done on the bearings is the clearance between the crank case and the ball bearing at the gear end. The clearance between this bearing and the crank case must not be over 0.001 of an inch, or just so it is possible, when the main bearings are fitted, that it can be revolved by hand. Before placing the main-bearing shells in the crank case, lay the crank shaft with the thrust bearing and the gear end ball bearing (assembled) in the upper half of the crank case. Blue the outside shell of the ball bearing at the gear end and revolve it by hand in order to find how the bearing fits the case. Remove the crank shaft and examine the markings made by the bluing. All high spots must be carefully scraped until a good bearing is obtained. Also, examine the ball race for high spots and smooth down wherever necessary with a fine file. When this ball race is fitted to the case, it is then possible to fit the main bearings. Take the shaft out, put the bearings in place, blue the journals of the crank shaft and place it on the bearings in the case. Revolve the shaft to mark the bearings and, at the same time, note the amount of clearance between the ball bearing and the crank case. Judge how much scraping is needed to bring this bearing down to its proper place. Remove the crank shaft and proceed to scrape the high spots, being careful to keep the crank shaft parallel to the crank case, that is, one

end not higher than the other. At the same time, be careful that neither the ball bearing nor the thrust bearing does not bottom. Regulate the amount of scraping by the clearance of the ball bearing until a good bearing is obtained with the proper clearance between the ball bearing and the crank case. New bearings are usually sufficiently oversized so that at first much scraping is necessary, but when arriving at the critical point, where the bearings are started to show up well in the marking, care must be taken that neither the ball bearing nor the thrust bearing become jammed. On the other hand, too much clearance in either of these bearings will spoil the proper operation of them. When all of the bearings are properly scraped, they should turn by hand. When the bearings are properly fitted in the upper portion of the crank case, reblue the crank shaft and place it on its bearings. Then place the lower half of the crank case with its bearings assembled on the upper half. Put all the crank case nuts on and tighten down gradually. Occasionally, turn the crank shaft, until the friction of the bearings tightens the shaft to a degree until it can hardly be turned. Be very careful not to tighten the case more in one place than another to avoid springing the case and obtaining a false impression upon the bearings. Revolve the shaft several times, to mark the bearings well, and remove the lower portion of the crank case. Note the impression made upon the bearings, scrape the high spots down until a proper bearing is obtained. To accomplish this it may be necessary to place on the case several times for remarking. This type of motor requires a fit of all bearings in the lower portion of the crank case at one time, just as is done when fitting a single cap bearing on other types of motors. The clearance desired on the main bearings is from 0.0015 to 0.002 of an inch. After the bearings are well scraped, that is, a good impression is obtained on both the upper and lower shells of each bearing, park the crank case and remove the crank shaft. The bearings should then be burnished with a smooth dull-edged tool. Then again bolt the crank case together with the crank shaft in place. It must be possible to rotate the crank shaft with very little effort; that is, easily with one hand. It is necessary to again remove the crank shaft to fit and assemble the connecting-rod bearings. Assemble the crank case again to prevent damage to the bearings while this is being done. Place the crank shaft in a suitable stand.

FITTING THE CONNECTING-ROD BEARINGS.

The connecting-rod bearings are of the bronze-backed, babbitt-lined, split-in-the-middle, nonadjustable type. The inside surface of the bearing runs against the crank throw, forming a bearing for one of the connection rods of a pair. The other companion con-

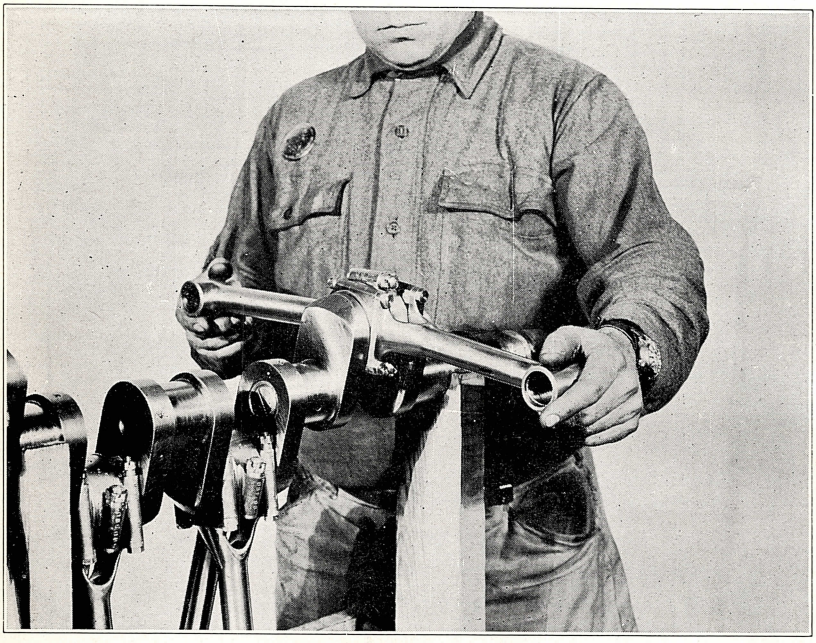


FIG. 5.

necting rod uses the outside of the bearing for its mounting. The inner connecting-rod bearing should first be fitted to the crank shaft. Do not under any circumstances remove any metal from the connecting-rod bearing or bearing cap where they join together, as this will spoil the fit of the outside connecting rod, which runs directly on the bronze. On new bearings the babbitt lining running against the journal of the shaft, together with the cap, are machined smaller than the shaft, thus leaving metal to be reamed out or scraped out during the fitting. The proper fit of this bearing is 0.0015 of an inch loose on the shaft diameter. The end clearance, between the inner connection rod and crank shaft, should be 0.009 of an inch. After the inner connection rod is fitted to the crank shaft and locked in place the outer rod can be placed over it. This rod must be fitted 0.003 of an inch loose on the diameter with 0.007 of an inch end clearance on the inner rod. Attention is again called to the fact that all bearings, bearing caps, connection-rod bolts and nuts are all numbered and must be replaced exactly as they were removed so that the numbers correspond. After the connecting-rod bearings are fitted, try each rod to see if it will fall of its own weight, as it should. Attempt to detect any binding, as the fit must be easy and uniform when turning slowly by hand, with no noticeable change in friction. Take one rod in each hand and again try for uniform fit. See that there is no variation in the friction. A binding is due to one or more of four things—too tight (the general cause), interference at ends, rough places, or sprung rod. Much care must be taken when remedying these ailments. The bearings even when new are necessarily very free, and after being worn can not be taken up, but have to be removed. In case a sprung rod is found, unless the proper tools are available for straightening, replace the rod with a new one. All nuts must be properly cotter-pinned upon completion of the bearing fitting. When the connection-rod bearings are all fitted examine the piston pins for proper clearance.

FITTING PISTON PINS.

The piston pin must be a tight fit in the piston (an easy drive fit); the piston a free fit over the head of the connection rod. The inside diameter of the connecting-rod bushing is reamed to 1.1812 inches and the outside diameter of the pin is 1.1810 inches. This allows 0.0002 of an inch freedom and should never be less. The end play of the connection rod at the piston pin should be about three thirty-seconds of an inch. If the piston pins are found not to measure up to these specifications, new pins and bushings will be necessary. New pins should never be used unless new bushings are used, and vice versa.

ASSEMBLING THE CRANK SHAFT, CONNECTING RODS, THRUST BEARING, AND BALL BEARING IN THE CRANK CASE.

The crank shaft with the thrust bearing, ball bearing, and the connection rods, minus the pistons, are all assembled on the crank-shaft stand before the crank shaft is placed in the crank case. To put the crank shaft in place, two men are needed, one at each end of the crank shaft. Each holds one end of the crank shaft with one hand and with the other hand guides the connecting rods into their proper openings in the crank case, being careful not to mar or jam the bearings in any way. Before the lower half of the crank case is bolted to the upper half, the oil-pump assembly, the pressure-regulating valve, the pump drain plug, the oil-pump screen, the plug in front of the crank case, the pressure-gauge connection and the oil auxiliary tank connection should all be assembled and placed. To make the crank case halves oil-tight, it is necessary to cover the surface of one half with a light coating of shellac. The shellac should coat the case evenly and then be allowed to dry about five minutes before putting the case together. When this is finished, bolt the two halves of the crank case together.

ASSEMBLING THE PISTONS TO THE CONNECTING RODS.

Place a piston over a connecting rod with the piston-pin lock ring slid down on the piston, so that it will not interfere with the entry of the piston pin. Drive the piston pin in place with a piece of brass or wood as shown in the figure. Then slide the locking ring back in place. The pistons on one side of the motor should be attached to their connection rods and then the cylinders of that side placed before the pistons on the opposite side are mounted. Turn the motor stand partly over so that the side of the motor being worked upon is in a vertical position. The next operation is to place the cam shafts. Replace the timing disk and scale. To do so, it will be necessary to attach the special hub, and find the correct top center of No. 1 L cylinder with the top center indicator, as previously stated during the disassembly. When this is accomplished, turn the engine in the proper direction or rotation until top center for No. 1 left cylinder is reached, continue past top center until the timing disk shows 10° past. This is the position of the crank shaft when the exhaust valve closes and the intake valve opens. With the crank shaft in this set position relative to No. 1 left cylinder, mount the cam shaft. In placing the cam shaft, with its gear attached, put it so that the " fall " of the exhaust cam and the " rise " of the intake cam are parallel with the valve tappets of No. 1 L cylinder. The noses of the cams will be pointing downward to each side. With the cam shaft so set, tighten securely the six hold-down nuts on the three cam-shaft bearings. A slight looseness will cause considerable

FIG. 6.

variation in timing. Turn the motor around one exact revolution producing top center No. 1 L cylinder, compression stroke. Check the valve-tappet clearance with the special gauge supplied with each tool kit. The clearance of the valve tappet should be 2 millimeters, or 0.078 of an inch. When the proper clearance has been given both the intake and the exhaust valve of No. 1 L cylinder, revolve the motor to 10° past top center on the intake stroke, or the position where the exhaust valve should close and the intake open. Now, check the timing of the cam shaft. To do this, turn the motor backward until a cigarette paper can be placed between the exhaust valve tappet and the cam. Then, turn the motor in the direction of rotation slowly, at the same time trying to pull the cigarette paper from between the valve and cam. When this can be done without tearing the paper, instantly cease turning; the exhaust valve has just been closed. Make a reading of the timing disk, and if it has been found that the exhaust valve closed within 1° of its proper place, the cam shaft has been set correctly. If it has been found that the exhaust valve did not close within 1°, the timing is not correct, and will have to be changed. A table is given to show the possible changes and simplify the process. When noting the timing as given on the timing disk, compute how many degrees the cam shaft is mis-timed, then refer to the table and find the most convenient way of correcting the defect. Special provisions have been made for correction of timing in the design of the cam-shaft drive. The vertical shaft is driven from the gear at its lower end by a screw-driver type of joint, the tongue of which is so located, in respect to the teeth of the upper gear, that a change of one-half turn of the vertical shaft gives a change in timing equivalent to one-half tooth of the cam-shaft gear. The cam shaft itself is driven from a gear by a key placed in one of the five keyways provided in the cam shaft. By changing the key one keyway, a change in timing is made equivalent to one-fifth of a tooth of the cam-shaft gear. The value of each tooth of the cam-shaft gear is 20°. If the cam shaft is found to be 20° early or late, by changing the cam shaft one tooth in the proper direction, it will correct the trouble. Again, the value of one key in the cam shaft is 4°, and if the cam-shaft gear is found to be 4° early or late, then by changing the cam shaft one keyway in the proper direction the trouble will be corrected. The value of one-half turn of the vertical shaft is 10°, and if the vertical shaft is changed one-half turn a change of 10° will be effected. At times it will be found that the cam shaft is out possibly 6°, 8°, 14°, or 18°, either one way or the other, making it necessary to use a combination of one or two changes; otherwise it will not be possible to arrive at the correct timing. For instance, if the cam shaft were out 2°, the smallest value is 1 keyway, which equals 4°, or too much for the correction. But, the value of the vertical shaft is 10°, consequently

if the cam shaft is retarded 3 keyways it will have changed the timing 12°, and then, if the vertical shaft is moved one-half turn in the opposite direction, the error is corrected.

ASSEMBLING THE CYLINDER BLOCKS.

Replace the cylinder-block gasket over the crank-case studs. A special ring clamp is used by which the rings can be clamped together to make the assembly block easier when being placed on the crank case. Before this special clamp is placed the ring openings must be equally spaced on the circumference of the piston. The opening of the ring, which holds the piston pin in place, must not come at either of the piston pin ends, and the pistons must be so set, by revolving the crank shaft, that two of the pistons are slightly higher than the other two. The pistons and cylinder walls must be thoroughly oiled before an attempt is made to place the cylinder blocks. This oil should be wiped on with the hand, so as to detect any foreign matter that may be on the piston or cylinder walls. In replacing the cylinder blocks it is assumed that the vertical shaft, vertical shaft housing and valves, have been thoroughly inspected, overhauled and reassembled. To replace cylinder block three men are needed, two to guide the cylinder block and one to guide the ring clamp and pistons and to watch that no rings are damaged during the assembly operation. More care must be taken in placing the block in this case than placing the cylinders on other motors. The cylinder block is very heavy, and if allowed to drop quickly on the rings the rings will be easily broken. When the rings of all the pistons have entered the cylinder block and the block nearly down upon the crank case, the vertical shaft joint must be coupled up and the cylinder gasket smoothed out, with no part turned under or doubled up. Otherwise, a misformed gasket will cause one side of the cylinder block to be higher than the other side. If this occurs, and the cylinders be drawn down in place, the flanges of the cylinder will be distorted, with a consequent leakage of oil. When the cylinder block is down on the crank case, put on all the hold-down nuts and tighten them gradually, all around, until all are of the same tension and as tight as possible without stripping the threads, attach the four vertical shaft housing nuts, then turn the motor stand around until the other half of the motor is in the vertical position and assemble the other block in the manner previously described for the first one.

REPLACING THE MAGNETO SUPPORT BRACKET AND OIL SUMP PUMP ASSEMBLY.

This bracket is held in place by seven studs. In replacing it turn the magneto drive shaft around until the spline of the shaft enters

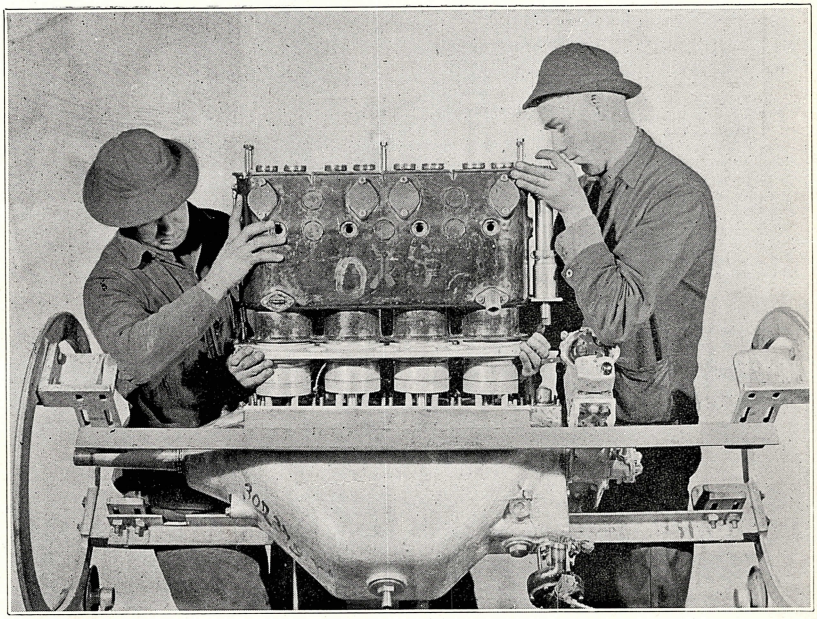


FIG. 7.

its place in the crank shaft, then tighten the seven stud nuts evenly. A gasket is used between the magneto support and the crank case. Before placing the support this gasket should be inspected and if found defective should be replaced. Next replace the breather pipe. It is more convenient in assembling the magneto support if the magnetos are left off of their bases. The support is attached at this time in order to close the opening to the crank case, thus keeping foreign matter out while the balance of the assembling operation is performed.

TIMING THE VALVES.

Since this is a difficult engine to time, much trouble can be saved if, when disassembling the engine, the vertical shaft gear, the key in the cam-shaft gear, and the vertical shaft spline are marked on both cylinder blocks, provided of course that the valve timing is found to be correct prior to the disassembly. In the event that the above is not possible the procedure for timing the motor would be the same as though new parts were installed with no marks available. Now cylinder blocks have been installed along with the vertical shaft and the vertical shaft gears. Three keyways; 12°, one-half turn of the vertical shaft; 10° of the cam shaft minus 10° of the vertical shaft gives 2° timing change. By referring to the table various combinations are plotted out and can be readily understood.

TABLE FOR ADVANCING OR RETARDING THE TIMING OF THE CAM SHAFTS.

To advance the cam shaft, rotate the gear on the cam shaft clockwise; to retard, counterclockwise. This is standing at the rear of the engine looking toward the propeller end. The following table is given to advance the cam-shaft timing. To retard the cam shaft, reverse the operation.

Degrees on timing disk on crank shaft.	Minutes on 360-mm. diameter timing disk on crank shaft.	
2	6.28	Advance 3 keyways and retard one-half turn vertical shaft.
4	12.57	Advance 1 keyway.
6	18.85	Advance 4 keyways, retard half turn vertical shaft.
8	25.12	Advance 2 keyways.
10	31.41	Advance one-half revolution of vertical shaft.
12	37.70	Advance 3 keyways.
14	43.98	Advance 1 keyway and one-half turn vertical shaft.
16	50.26	Advance 4 keyways.
18	56.55	Advance cam-shaft gear 1 tooth and the vertical shaft one-half turn. Retard cam-shaft gear 3 keyways.
20	62.83	Advance 1 tooth of cam-shaft gear.
40	125.66	Advance 2 teeth of cam-shaft gear.

Value of 0.001 of an inch valve clearance equals 3° crank shaft travel.

CHECKING THE TIMING ON REMAINING VALVES AFTER SETTING CAM SHAFT.

When the cam shaft has been timed within 1° of the proper timing, proceed to check the opening and closing of every valve of the cylinder block. The proper timing is as follows:

(*a*) Intake opens 10° after top center.
(*b*) Intake closes 50° after bottom center.
(*c*) Exhaust opens 45° before bottom center.
(*d*) Exhaust closes 10° after top center.

Occasionally it may be found that with the proper valve clearance (0.078 of an inch) one or more valves may close or open too early or late. If such a defect is not over 3°, it is permissible to change the valve clearance to correct. If it is over 6°, the cam shaft should be replaced. It is more imperative that the exhaust valves close and the intake valves open on the specified timing (*a*) and (*b*) above, than the opening of the exhaust valves and the closing of the intake. An exhaust valve opening and intake closing should operate at least within 3° of their proper places.

CORRECTING VALVE TIMING BY AID OF CLEARANCE.

The proper duration of the various cycle strokes is as follows:

(*a*) Intake, 220°.
(*b*) Compression, 130°.
(*c*) Power, 135°.
(*d*) Exhaust, 235°.

Should it be found that the exhaust valve opening period is slightly more than 235°, and that the closing of the exhaust is later than it should be, increasing the valve clearance will correct this trouble. The value of 0.001 of an inch-valve clearance is 3°; therefore, if it is found that the exhaust valve is closing late by 3°, a change of 0.001 of an inch-valve clearance will make the correction. On the other hand, if the exhaust valve is closing too early, by increasing the clearance the trouble can also be corrected. It must be remembered, though, that when changing the valve clearance the opening as well as the closing is affected. A cam-shaft, therefore, that is more than 3° out, and must be used, as a new shaft is not available, should be so balanced that the defect will be divided two-thirds at the opening of the valve and one-third at the closing. If the cam-shaft is found to be correct within 3°, favor the closing in preference to the opening.

COMPLETING DETAILS ON A CYLINDER BLOCK AFTER TIMING VALVES.

After the cam shaft and the valves are properly adjusted on the left block, be sure that all hold-down nuts are tight and cottered, as well as the cam-shaft gear nut. Oil the cams and tappets liberally; replace the valve cover, being careful that the gasket is in good condition. If the vertical shaft housing has been loosened to change the timing of the vertical shaft, screw it back into place with the spanner wrench provided in the tool kit and lock the nut with the lock wire. Be very careful to line up the hole in the nut with either one of the holes in the vertical shaft pinion bushing. Slide the base of the housing down in place and put on the four hold-down nuts. Tighten packing gland enough in center of vertical shaft housing to make it oil tight. This completes the assembly and timing of one cylinder block.

ASSEMBLY OF THE RIGHT CYLINDER BLOCK.

After the left cylinder block is completely assembled, turn the right side to the vertical position. Revolve the crank shaft until exhaust-valve cylinder No. 1 L just closes; note the timing disk and turn the crank shaft exactly 90° farther. This position is the exhaust-valve closing-point cylinder No. 4 R. Proceed to time the cam shaft of this cylinder block in the same manner as stated for the left cylinder block, using cylinder No. 4 R as a basis. Check the valve timing and the tappet clearance likewise, then securely fasten the cam-shaft gear bearings, making sure the nuts are tight and cotter pinned, and that the cam-shaft gear nut is also tight and cotter-pinned. Assemble the vertical shaft housing, using the same care as taken from left side. Liberally oil all parts and replace cam-shaft cover, which completes the installation of the cylinder block and the cam shaft assembly of this side.

PLACING AND TIMING THE MAGNETO.

The magneto support has been attached without the magnetos upon it. It is now necessary to attach the magnetos. One magneto is driven in a clockwise direction and is attached to the left side of the engine looking at the gear end. (A clockwise magneto is one where its driving coupling turns clockwise when viewed facing magneto.) The other magneto is driven in a counterclockwise direction and is attached to the right side of the engine. Turn the motor in the proper order of rotation until 20° 20′ before top center, compression stroke, No. 1 left cylinder. At this point the breaker points of the magnetos should just break, and the distributor brushes should be making contact with the segment of the distributor wired to No. 1 left cylinder. To mechanically set the timing, set the piston in

position as stated for No. 1 L cylinder and set either of the magnetos on the magneto support.

The motor is equipped with a special magneto coupling that has a male and female gear, and is so designed that when a cotter pin is withdrawn from the center of the coupling the coupling may be moved back far enough to throw the gears out of mesh. Bolt the magnetos in place with the four studs, being careful that no dirt is under the magneto base. Remove the distributor and breaker covers of the magnetos. One at a time will have to be set. Slip the coupling back and turn the magneto in the proper direction of rotation until the distributor brush is making contact with the segment of the distributor block wire to No. 1 left cylinder, the distributor wires being connected as stated before. Incidentally, these wires are all lettered with a small brass clip fastened around them above the magneto.

Continue to turn the magneto until the breaker points just start to break. This is best determined by placing a strip of cigarette paper between the breaker points, and when the paper can be withdrawn easily the points are just breaking. Of course, breaker points must be adjusted before any timing is attempted, the proper setting being 0.020 of an inch. The 0.020 of an inch can be obtained by using the magneto gauge supplied with the tool kit. When this critical position of the magneto is obtained, allow the coupling to slide back and mesh the gears. After one magneto is set proceed with the setting of the other, and synchronize the last magneto so set with the one previously timed. This means that both magnetos must fire the same cylinder at exactly the same time. Trace out the wires leading to all cylinders and attach them as shown in the diagram, thus completing the ignition system. Do not fail to replace the two large cotter pins passing through the center of the magneto couplings. Otherwise, when the motor is started the couplings are liable to slip back and charge the timing.

ASSEMBLING THE INTAKE MANIFOLD AND CARBURETOR.

The flanges of the intake manifold should be thoroughly examined for nicks and scars, and if a surface plate is handy, blue the surface plate and rub the flanges of the intake manifold on the plate to make sure the flanges are not sprung. If they are found to be sprung slightly, correct by filing with a fine file. Be careful not to remove too much metal. The intake manifolds should then be placed on their respective cylinder blocks, being careful that the gaskets are good; if they are not they should be replaced. Tighten down the four stud nuts on each manifold evenly on one side, then the other, so as not to distort the flanges. The manifold T with the carburetor attached can now be slid in place. The same care should be taken

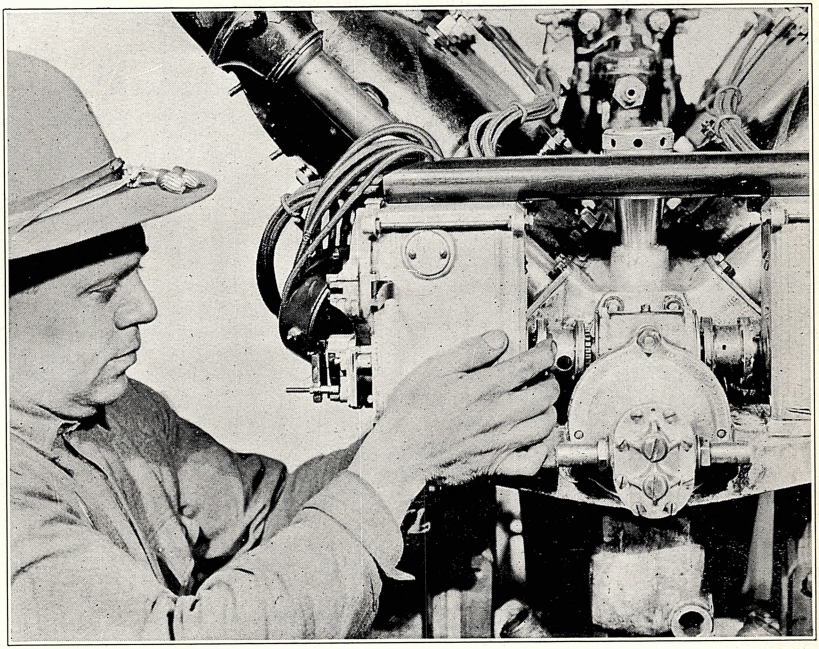


FIG. 8.

with the gaskets and flanges connecting the T to the manifolds as was taken when connecting the manifolds to the cylinder blocks. A slight air leak at any one of these joints will cause considerable trouble when the motor is installed in the airplane, and great care should be taken that all of the manifold joints are absolutely air-tight.

ATTACHING THE GEAR-TYPE OIL PUMP.

The gear oil pump is located on the gear end of the engine, it being bolted to the magneto support bracket, and is driven by the same shaft that drives the magneto drive shaft. It is fastened with three studs and two dowel pins to the magneto bracket. Now, if the pump has been cleaned, inspected, and assembled, as stated above, all that is necessary is to inspect the companion flange surfaces of both the pump housing and the magneto bracket. Provided both are clean and not nicked or marred in any place, and the gasket which goes between the two surfaces is good, bolt the pump in place.

ASSEMBLY OF THE WATER PUMP.

The water pump is held in place by two studs which go through the bracket underneath the oil-vane pump, and is coupled up to the same shaft that drives this oil pump by a male and female square shaft coupling. Mount the pump on its bracket so that the small tube union fitting will point toward the rear of the engine. The oil pump gland nut can not be tightened until after the water pump is assembled on the crank case, and should then be only lightly tightened just so no leak will occur, but should not be enough to cause excessive wear on the shaft. After the packing gland is tightened sufficiently, lock it in place by tightening the locking screw on the water-pump bracket. This jam screw should never be tightened hard enough to create any pressure against the packing gland, but the head of the screw should jam against the bracket simultaneously that the point barely touches the packing gland in one of its slots. The same care should be exercised in tightening and locking the packing gland of the water pump. Connect the small tube between the water pump and the intake manifold T.

CONNECTING THE WATER MANIFOLDS.

The water-pump manifolds are connected by flanges at one end to the cylinder block, and by a short piece of hose to the water pump. When connecting up the hose, make sure the ends of the hose are not doubled up inside, especially when placing over the connection on the water pump. Tighten the hose clamps sufficiently to prevent leakage. Before the flanges are attached to the cylinder blocks

they should be inspected to see if their surfaces are smooth. If the old gaskets are used, make sure they do not double under when placing the manifolds. Tighten the flanges sufficiently to prevent leakage.

PLACING THE PROPELLER HUB.

Remove the special timing-disk hub and replace the proper hub for the motor. Note that the hub number corresponds to the motor number, as hubs must not be interchanged. There are two classes of propeller hubs, one class has a double nut and the other class a single nut. The process of replacing each class of hub is as follows:

(*a*) Replacing the double-nut type: Fit a wrench to the smaller nut and start turning it in right-handed. Turn until the hub is sufficiently tight, then screw the larger nut in, also right-handed, until it is tight. Both nuts are locked by a locking wire which goes completely through the larger nut and into a hole in the smaller one. Incidentally, there are six holes in the smaller nut, one opposite the center of each flat. The larger nut will have to be revolved until the hole in it, for the locking wire, is directly opposite one of the holes in the smaller nut. When both nuts are tightened as much as possible, and the holes in both nuts are opposite, insert the locking wire. Due to the difference in the threads of both nuts, one nut can not back off by itself nor can both nuts back off together with the locking wire properly in place.

(*b*) Replacing the single-nut type: The single nut is threaded both inside and out. The outer thread is a fine thread (9 to the cm.) and screws into the propeller hub. The inner thread is a coarse thread (5 to the cm.) and screws on to the crank shaft. To attach the hub, both these threads have to be started practically at the same time. Before mounting the propeller hub, screw the nut three turns into it, then place the hub on the crank shaft and start the coarser thread screwing on to the shaft. Note particularly that the coarse thread should start when the fine thread has been screwed in about three turns. Tighten up the nut, and when as tight as can be drawn, not more than one-eighth of an inch space should show between the propeller hub and the nut flange. Neither should the nut screw up all the way and now show space between it and the hub.

CONCLUSION.

The complete assembly has now been accomplished and the motor is ready to be taken to the test block, where it should require but a few minor adjustments, such as adjusting the carburetor, if the proper inspection and assembly has taken place.

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